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Modern Fruit Production

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Modern Fruit Production

by **JOSEPH HARVEY GOURLEY**

HORTICULTURIST · THE OHIO AGRICULTURAL
EXPERIMENT STATION

PROFESSOR OF HORTICULTURE · THE OHIO
STATE UNIVERSITY

& **FREEMAN SMITH HOWLETT**

ASSOCIATE HORTICULTURIST · THE OHIO AGRICULTURAL EXPERIMENT STATION

ASSOCIATE PROFESSOR OF HORTICULTURE ·
THE OHIO STATE UNIVERSITY

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PREFACE

Orcharding and small fruit culture represent a major phase of American agriculture, both domestic and export. With the intensified development of the industry, the science of horticulture becomes more complex, and the professional horticulturist, the student, and the grower all feel the need of additional training and a ready source of recent research. Not only the American, but also the foreign, literature is increasing rapidly, and every branch of study demands consideration.

The student of fruit culture, whether in or outside college, should have a grasp of general concepts. He should strive to interpret physiology, morphology, soils, chemistry, and other fundamental sciences in terms of fruit plants and their products. The authors hope that they have presented the fundamentals in such a way that they become of vital concern to the serious student. At the same time, they have endeavored to present the most acceptable practices of American fruitgrowing.

Pomology has developed into a science in its own right, similar in its fundamental background to other plant sciences. The horticulturist must always remember, however, that he is the representative of a vast industry, and that his scientific efforts and leadership must be based on practical considerations. No effort is made, therefore, to force scientific data into this text except as they form a basis for modern fruit production.

The general subject of insect and disease control has not been included in this volume. The field is so extensive and specialized as to lie outside our immediate purposes; hence only incidental reference is made to sprays and spray practice.

The present volume represents a complete rewriting and expansion of the *Text-Book of Pomology*. While a few portions of it remain much the same as they were in the original text, by far the major portion of material is entirely new both as to American and foreign sources.

Acknowledgments

The authors of this work have drawn freely upon the published material of their associates in the general plant field. Although no attempt or pretention has been made to cite all acceptable literature dealing with a subject, yet the authors have endeavored to select such representative experiments and data as would assist the reader to a better understanding of the problem. Fellow workers have been most helpful either in reading portions of the text or in offering suggestions through correspondence, and also in furnishing illustrative material. Our sincere appreciation is hereby expressed.

We are particularly indebted to Dr. J. R. Magness for a critical and helpful reading of the entire manuscript. Special assistance and courtesies have been extended by Dr. F. P. Cullinan, Dr. R. M. Smock, Dr. Leon Havis, Professor F. H. Beach, Dr. Reid M. Brooks, and Dr. L. D. Baver. Two of our students, Wesley P. Judkins and David Allmendinger, assisted in the compiling of data and the checking of literature. To Jean W. Howlett the authors are indebted for her constant help and criticism in the preparation of certain chapters.

The drawings used in Chapter 2 were made by Mr. Robert M. Gatrell of the Department of Fine Arts, Ohio State University, unless otherwise noted.

J. H. G.
F. S. H.

WOOSTER, OHIO
January, 1941.

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1

THE FRUIT INDUSTRY

The culture of fruit plants is rooted in antiquity. Probably throughout all history, fruits have been regarded at once as a necessity and a luxury, and their intensive cultivation has always followed in the wake of advancing civilization. Indeed all fruitlore is found to be closely intermingled with the history of wandering tribes and established cultures.

The early colonists to America brought with them seeds, trees, or plant parts from their native lands, and fruit growing established itself along with the early settlements. Travelers, priests, missionaries, and such characters as Johnny Appleseed (John Chapman) extended the frontiers of fruit culture and at the same time were the chief means of disseminating varieties. The student must look elsewhere for the history of fruit growing. He will find it a most intriguing field of reading and research.

Fruit Production in the United States

The total production of the different fruits in the United States is shown in Table 1. That apples lead all on a 5-year basis (1928–32) is shown, although in certain years (e.g., 1936) citrus fruits are far in the lead, and this latter trend will continue for a time. Citrus ranked second, grapes third, and peaches fourth in the United States in the 5-year period 1928–32. These four contribute about 85 per cent of the total fruit tonnage each year.

Because of the favor with which citrus fruits have been received on the American table, their rapid rise in production is not surprising. The apple has had to adjust its acreage to the new demand rather than the reverse. The United States crop of citrus fruits was 135 million boxes in 1938–39 as compared with 55 millions for the 1925–29 period. Much of this rate of increase is due to new production in Florida and Texas.

TABLE 1. FRUIT PRODUCTION IN THE UNITED STATES IN TONS*

	Total Production (tons) Average 1928–32	*1936*
Almonds	12,200	7,600
Apples	3,871,992	2,592,744
Apricots	227,000	248,000
Cherries	116,704	115,160
Citrus	2,792,410	3,349,727
Cranberries	29,461	25,215
Dates	1,318	3,970
Figs	17,100	20,000
Filberts	296	1,850
Grapes	2,214,482	1,916,460
Peaches	1,354,824	1,106,832
Pears	578,650	602,750
Pecans	31,000	20,072
Plums and prunes	365,843	310,800
Strawberries	209,160	180,180
Walnuts	35,290	42,900

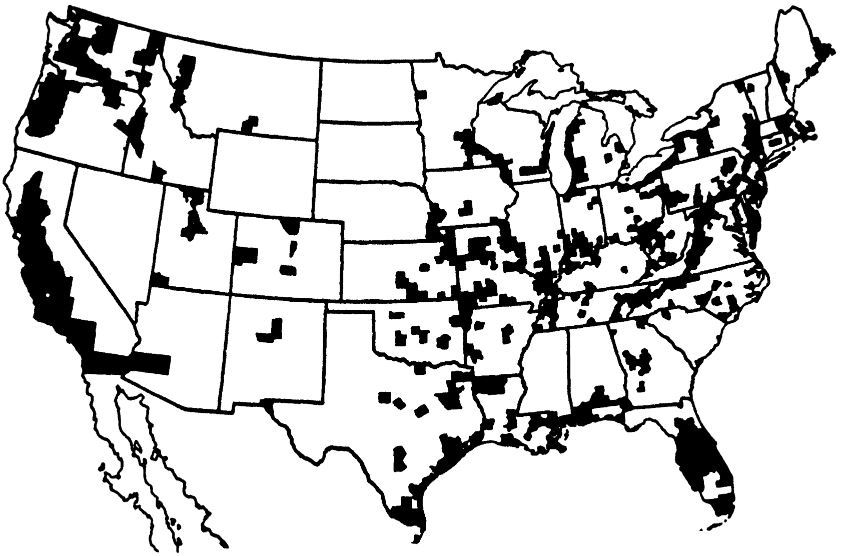
Fruit-Producing Sections of the United States

The accompanying map (Fig. 1) is a composite of the chief fruit-growing regions of the country. That these regions are segregated is obvious. The abandonment of unfavorable sites is increasing, and the production of fruits is moving toward large bodies of water, favorable topography, suitable soils, and toward sections of favorable economic conditions. It is safe to predict that this trend will continue; in fact, the reduction of total acreage is one of the real needs of the fruit industry. "At present California contributes one-fourth of the Nation's acreage of fruits and nuts and nearly one-half of the value. Southern California grows mostly citrus fruits, walnuts, grapes, and apricots; central and northern California produce grapes, peaches, apricots, plums, and prunes, with some citrus fruits and pears in the foothills, and apples near the cool coast." [2] Florida produces mostly citrus fruits; Georgia and the Carolinas are heavy producers of peaches; the Gulf States produce most of the pecans and strawberries; western New York and western Michigan, apples, grapes, and peaches. Elsewhere with few exceptions the apple is the dominant fruit. Because of the dry winters and occasional summer drought almost no fruit is grown in the Great Plains.

The first apple areas were located along the south shore of Lake Ontario and the Hudson Valley in New York, on the sloping hillsides of southern New England, and in the Shenandoah Valley of

*From Agricultural Statistics. U. S. Dept. Agr., 1938.

Virginia. For several decades these four regions continued to produce practically all of the apples consumed in the United States and also provided for the export trade which had developed. Later, fruit was planted commercially in Ohio, Illinois, Michigan, and elsewhere in the Midwest, until by the turn of the century the valleys of Yakima and Wenatchee in Washington began to take on a semblance of what today is the greatest apple-producing area on the North American continent.



(Courtesy *American Fruit Grower*)

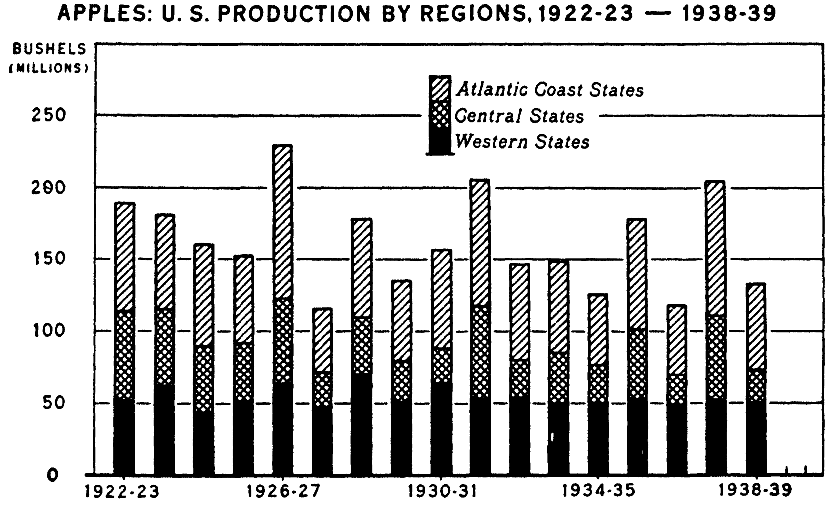
FIG. 1. Generalized map of fruit-producing areas of United States including all fruits.

Apples. At the present time the major apple districts of the United States can be grouped as follows: *Eastern District*—the New England states; New York; the Middle Atlantic coast states including New Jersey, Delaware, Maryland, Pennsylvania, and the Virginias. *Middle Western District*—the North Central states of Michigan, Ohio, Indiana, and Illinois; and the Ozark region including Arkansas, southeastern Nebraska, and eastern Kansas. *Western District*—the Rocky Mountain area of Colorado, Utah, Arizona, and Idaho; and the Pacific Coast states of Washington, Oregon, and California. Baker and Genung[2] state that "Most of the apple trees in the East are located in the Appalachian Mountain and Piedmont region, and around the shores of the Great Lakes where spring frosts are less injurious than in the interior, because of lake influence or mountain air-drainage protection. The southern limit of the apple region extends only a little beyond the northern limit of cotton, and the western or moisture limit is about the same as that of timothy. Most of the apples tree of the West are in irrigated valleys." It is significant to note that in 1909 there were only a few scattered plantings in Washington, while New York was by far the heaviest producer in the country. Several factors favored the growth of the apple and pear industry in Washington; namely, the building of irrigation systems, the climatic and soil factors, and the enterprise of a group of people interested in developing a new industry. The dangers of spring frost were not a serious hazard, and injurious insects and diseases were not abundant at first. Bacterial diseases were practically unknown in what had recently been desert country. As the tree population increased insect problems, particularly codling moth, increased until they became a most serious hazard. Markets were far away from the Western fruit sections, to be sure, but the advent of the modern refrigerator car and faster rail transportation reduced shipping problems to a minimum.

In the East the growers have been burdened with old orchards and old varieties; the export market to the British Isles has been gradually reduced, and the American public has shown a preference for apples of the quality of Delicious and Jonathan to those of Baldwin and Ben Davis. Finally, the severe winters experienced throughout the East in 1917–18, 1933–34, and 1935–36, killed or impaired hundreds of thousands of trees, so that a rebirth of the fruit industry in this section became imperative.

The statistics of the fruit industry vary considerably from year to year, especially the production data. Hence figures showing the fruit-tree population and the yield records for any given Census Year (or any other year) rapidly become antiquated, yet some general picture can be gained by examining these sources of information, and the student should consult new data as they appear.

As reported in the United States Census for 1935, there were in the country about 17½ million apple trees not yet of bearing age, and 82½ million bearing trees. The production for that year was about 177 million bushels. In comparing New York and Washington, the two largest producing states in the country, it becomes apparent that yields fluctuate more in the former state and that the average yield per tree is also lower. In 1935, for instance, there were in New York 1,415,257 trees not of bearing age and 7,683,831 bearing trees. At the same time in Washington only 858,531 trees of nonbearing age and 4,598,332 trees of bearing age were reported, and yet the latter state produces annually nearly twice as many apples as New York. The answer to this paradox is quite apparent in a comparison of the average yield per tree for both regions. In 1935, a good apple year the country over, New York state growers harvested an average of approximately 2.2 bushels per tree, while the Washington growers realized an average production of 6.6 bushels. Figure 2 shows the strikingly uniform production in the Western States during recent years.



U.S DEPARTMENT OF AGRICULTURE NEG. 34514 BUREAU OF AGRICULTURAL ECONOMICS

FIG. 2

The following figures were prepared for the 1938 Fruit Outlook Report.

Year	*Number of Bearing Apple Trees in U. S.*
1910	151,300,000
1920	115,300,000
1925	103,700,000
1930	88,800,000
1935	82,500,000
1940	74,000,000 (estimated)
1945	66,000,000 (estimated)

Pennsylvania with about 11½ million bushels and New Jersey with 4⅓ millions are responsible for the bulk of the apple production in the North Atlantic district, exclusive of New York. In the South Atlantic area over 70 per cent of the apples are grown in West Virginia and Virginia. West Virginia produces nearly 7 million bushels annually, and Virginia, about 13 million bushels, the latter being confined chiefly to the Shenandoah Valley. Figures for the North Central district comprise 6½ million bushels each for Michigan and Ohio, 2½ million bushels for Missouri, and 4½ million from Illinois. The total from these three states constitutes three-quarters of the production for this region. California with 10 million bushels, Oregon and Idaho with 5 million bushels each, produce 20 million bushels out of the total of 24 million (Washington excluded) in the Western district.

"There were one-fourth fewer apple trees in the United States in 1930 than in 1920. Particularly heavy was the decline in southern Maine, western New York (except two counties), the upper Ohio Valley, south-central Illinois, and the Ozark district of Arkansas. In the apple districts of western Oregon and Idaho and in most of those in Washington a notable decrease occurred mostly of trees of bearing age. Old, unproductive trees, mostly in farm orchards or on unsuitable sites, were cut down and generally not replaced with young trees." [2]

Fruit growing, like many other agricultural industries, tends to become localized. That is, fruit growing as a whole may be prevalent throughout the entire nation, but only a relatively small portion of a certain region or state may be devoted to the industry. Thus it is that the 1935 United States Census report shows that between a sixth and a seventh of the nation's apples are usually produced in but two counties of Washington; namely, Yakima and Chelan. In these foremost counties 21,173,908 bushels were harvested from 3,118,629 trees in 1934. During the same year Wayne and Niagara counties of New York were next with a total of slightly over 5 million bushels.

Grapes. In the Eastern part of the country grape growing was established at an early period, mostly in Ohio and New York. In California the Spanish Mission Fathers introduced European grape varieties and at the present time this state produces 86 per cent of the total crop of the United States, about 2,000,000 tons in the average year. The following states outside of California make up the bulk of the remaining grape-producing regions: New York, 80,106 tons; Michigan, 62,587 tons; Ohio, 25,735 tons; Pennsylvania, 25,174 tons; Arkansas, 11,820 tons; and Missouri, 9,234 tons. About 22 per cent of the California tonnage is of wine varieties, 18 per cent table varieties, and 60 per cent raisin varieties of which only about three-fourths are dried. The leading counties in grape production are all in California: Fresno County which produced in 1934 over one-fourth of the total crop in the United States, was first with 570,275 tons; Tulare County was second with 254,179 tons; and San Joaquin, third with 228,821 tons.

Peaches. The peach regions are concentrated in California; Georgia; New York, Pennsylvania, and New Jersey; Ohio, Illinois, Michigan; North and South Carolina; Tennessee, Arkansas, and Texas; a few in Colorado; and a few in Washington. Nearly one-third of the peach trees of bearing age are in California and central Georgia. Both are early-peach districts, but the California crop is mostly canned. Since the price for fresh peaches has been favorable during the past 5 years, it has stimulated heavy planting in some areas, notably in the early-producing sections. The total average yearly production for the United States is about 56½ million bushels. California produces about 40 per cent of the total crop. The three leading counties are located in California and are, in order of production, Sutter, Stanislaus, and Fresno. The peach is particularly sensitive to cold weather, and consequently the production area is definitely limited. The influence of water is quite noticeable around the Great Lakes, particularly Ontario, Lake Erie, and Lake Michigan. "Cold, dry winters prevent peach production northwest of a line drawn from Chicago to Omaha and thence to Amarillo, Texas. . . . In the period 1920–30 the peach industry underwent some shrinkage. Two or three severe freezes within this period caused the killing of a large number of old trees, and prices of peaches were such as to discourage replantings. There was a notable decrease in number in eastern Texas and south-central Georgia, in the northern Virginia and Maryland area, in New Jersey and eastern Pennsylvania, in western New York, and the northern portion of the peach belt in Michigan, in the Ozark area, and in southern California." [2]

Pears. Pears constitute only 4.7 per cent of the total tonnage of the United States fruit crop per year. The three Pacific states, California, Washington, and Oregon produced 16,016,000 bushels or 69 per cent of the total crop. The other leading states are New York (the Ontario shore and the Hudson Valley) with 1,262,000 bushels, Michigan (Berrien and adjacent counties) 600,000 bushels, and Illinois, Pennsylvania, Ohio, Texas, and Colorado all with more than 300,000 bushels per year. Yakima County in Washington leads in production with over three million bushels produced in 1934. Jackson County (The Rogue River Valley) in Oregon is second, with approximately 1,700,000 bushels, and Santa Clara County in California is third with 1,500,000 bushels.

Plums and prunes. Ninety per cent of the entire plum crop is produced on the Pacific Coast. California (Santa Clara, Sonoma, Napa, Solano, and Placer Counties) leads the field with 15½ million bushels, Oregon (Marion, Polk, and Yanhill Counties in the Willamette Valley) is next with almost 4 million bushels, and Washington (Clark County) is third with 1½ million bushels. Prunes, dried for the market, constitute a large part of the production in these states, as only about 15 per cent of the plums and prunes from the western states are shipped fresh. Apart from this area, the remaining states produce very few plums and prunes. Idaho, however, is rapidly becoming an important center. In 1934 she harvested 450,000 bushels. The leading eastern fruit states such as New York, Pennsylvania, and Michigan produce between 100,000 and 200,000 bushels each. Santa Clara County in California has long ranked first in individual production with 5,600,000 bushels. Sonoma County of the same state is second with 1,352,000 bushels.[10]

Cherries. A 5-year average of cherry production, taken from 1928–32, represents only 0.9 per cent of total fruit tonnage. However, according to the 1935 Census, a marked increase, consisting of almost a million and a half bushels, has occurred since 1930, with Michigan leading in the number of trees and number of bushels produced. New York is second, with the three Pacific Coast states Washington, Oregon, and California running about even for third place. Door County in Wisconsin, which produced 251,616 bushels in 1934, leads the nation's counties in cherry production. The western counties of San Joaquin in California, and Yakima in Washington, as well as Wayne County in New York state, produced more cherries in 1934 than did their nearest Michigan rival, Grand Traverse. And yet at the same time

Michigan produced more cherries than any other state in the Union.[10]

In the West nearly all cherries are sweet varieties and in the East they are mostly sour ones.

General inventory of orchard fruits. The following special report from the Bureau of Census, 1935, summarizes quite concisely the relative importance of the principal fruits of the United States.

"The outstanding changes in tree and vine fruits on farms in the 5-year period from 1930 to 1935 were substantial increases in the number of cherry, grapefruit, and orange trees, marked decreases in the number of apple and peach trees, and moderate declines in the number of pear and plum trees and in the number of grapevines." [10] It is important also to note the decline during this period in new plantings for each of these fruits as evidenced by the number of nonbearing trees on the census dates.

From the standpoint of production trends, Taylor[8] points out that "apple prices have been low because the production of all fruits in 1937 was the largest on record. Fruit production has almost doubled since 1919 and is expected to continue upward as large acreages of trees are still to come into bearing or to reach maximum productivity. Apples are the only major fruit in which the United States is experiencing a declining tree population."

It is evident that the total quantity of fruit produced in the United States has increased to a greater extent during the past 20 years than has the population of the country. Including bananas, the amount increased from 196 pounds per capita, for the 1919–23 period, to 229 pounds per capita during the past 5 years. Notwithstanding increased fruit consumption, this additional production has resulted in supplies of many fruits in excess of the amount which can be marketed, at least under the existing purchasing power of the consuming public.[2]

Yet Magness has pointed out that "the apple industry today appears to be in the soundest basic position of any of the larger fruit crops of the United States from the standpoint of production trends. Some planting of orchards to replace old orchards which are now past their commercial peak seems desirable." [5]

Land in fruit orchards, vineyards, and planted nut trees. The combined areas of orchards, vineyards, and planted nut trees on January 1, 1935, amounted to 6,220,679 acres which represented an increase of barely 2 per cent over that reported on April 1, 1930. In addition to the fruits listed above, this acreage includes that for apricots, nectarines, quinces, figs, lemons, limes, kumquats, almonds, pecans, English or Persian walnuts, tungnuts, etc.

"In 1929 the total land in fruit orchards, vineyards, and planted nut trees was only about one-tenth that in wheat or hay. But the value of the fruits and nuts was about 78 per cent of that of the wheat crop and 66 per cent of the hay crop. The value of the fruits and nuts in that year was about two-thirds of that of potatoes, sweet potatoes, and vegetables combined, and the acreage was about the same."[2]

Trends in fruit consumption. "The trend in total consumption of fruit per person, though fluctuating widely from year to year, has remained more or less horizontal since the beginning of the century, at least. But a notable shift has occurred from apples to citrus fruit. The per capita consumption of apples has decreased from between 70 and 120 pounds a year during the pre-war years, varying with the season, to less than 60 pounds, on the average, during the last decade. The consumption of citrus fruits has increased from about 10 pounds annually at the beginning of the century to more than 40 pounds, on the average, during the last 5 years. The per capita consumption of oranges has increased fourfold in the third of a century, and of grapefruit from almost nothing to nearly 10 pounds. Consumption of grapes has increased from about 20 pounds a year at the beginning of the century to more than 30 pounds during most of the last 10 years, and the proportionate increase is similar for pears and prunes. Per capita consumption of peaches has remained more or less stationary, except for fluctuations from year to year."

This situation has been summarized in the Fruit Outlook for 1939 by the U. S. Department of Agriculture on a per capita basis from 1919 to 1938, as shown on page 11.

This illustrates in a forceful way the shift in consumption from apples to citrus and other fruits. Magness points out that "During the same period, production of citrus fruits has almost doubled, and during the past 5 years more total citrus fruit per capita than apples has been produced in the United States. This increase applies to all three of the main citrus fruits, although the greatest increase has been in grapefruit." [5]

Apple varieties and their distribution. The general public probably possesses a better knowledge of apple varieties than of any other

TABLE 2. PER CAPITA PRODUCTION OF VARIOUS FRUIT CROPS IN THE UNITED STATES

Crop	*1919–23*	*1924–28*	*1929–33*	*1934–38*
		(in pounds)		
Apples	17.6	68.4	61.2	56.8
Citrus, total	30.0	36.1	43.0	58.7[a]
Oranges	21.2	25.0	29.3	36.6[a]
Grapefruit	5.4	6.9	9.3	16.9
Lemons	3.4	4.2	4.4	5.2[a]
Grapes	31.7	39.8	33.3	36.1
Peaches	20.4	22.3	20.5	19.6
Plums and prunes	8.3	10.6	11.4	14.8
Pears	7.5	9.1	9.7	10.9
Apricots	2.8	2.9	4.0	3.4
Strawberries	2.8	3.5	3.3	3.0
Cherries	.8	1.4	2.0	2.1
Cranberries	.5	.5	.5	.4
Olives	.2	.3	.3	.4[a]
Total 13 fruits	176.6	194.9	189.2	206.2
Bananas—imports	19.6	25.0	21.2	22.7[a]

[a] Based on 4-year average.

fruits. A quarter of a century or more ago Baldwin and Ben Davis were the leading varieties in the East and many others of moderate quality were widely distributed. During this interval there has been a radical change in the status of certain apple varieties as well as in that of fruits in general. We find, for instance, that Delicious now leads all others, and Winesap, Jonathan, and Stayman Winesap are near the top of the list in popularity. McIntosh has made rapid strides in some sections, notably in the northeastern portion of the United States.

The chart shown on page 12 (Fig. 3) is adopted from the U. S. Department of Agriculture Bureau of Agricultural Economics. It tabulates, according to age and number, 25 leading varieties of trees planted in commercial orchards. Of trees under 9 years of age in 1927, Delicious, Winesap, Stayman Winesap, McIntosh, and Golden Delicious lead all others.

A recent survey of 44 widely distributed nurseries recorded those apple varieties showing the largest sale and revealed some interesting information. The results were not concerned with trees already planted but only with varieties having the largest sale at that time (1935). [1]

Of the early varieties Yellow Transparent was 2½ times in advance of the nearest competitor which, in the country as a whole, was Oldenburg. In the Southern states Red June was second. In

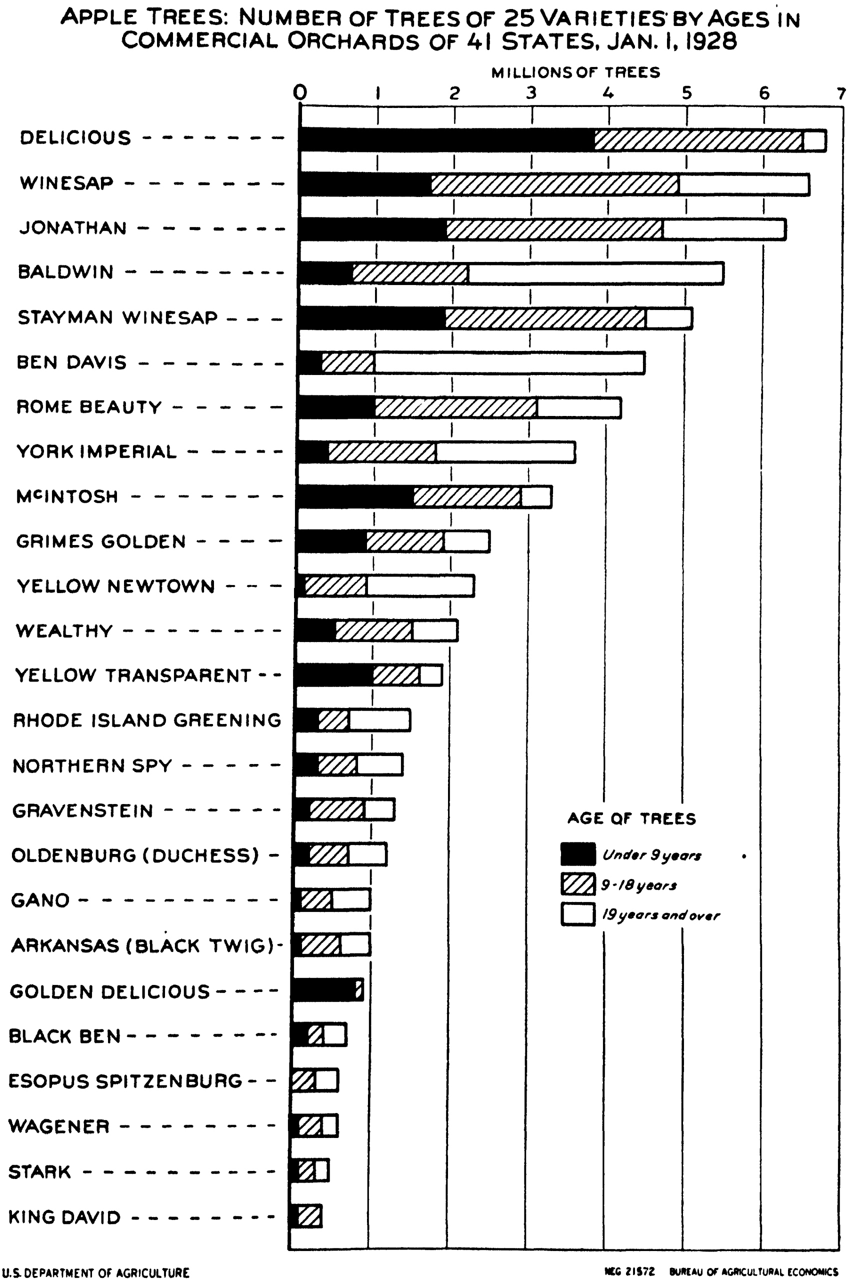

APPLE TREES: NUMBER OF TREES OF 25 VARIETIES BY AGES IN COMMERCIAL ORCHARDS OF 41 STATES, JAN. 1, 1928
MILLIONS OF TREES
0
1
2
3
4
5
6
7
DELICIOUS
WINESAP
JONATHAN
BALDWIN
STAYMAN WINESAP
BEN DAVIS
ROME BEAUTY
YORK IMPERIAL
McINTOSH
GRIMES GOLDEN
YELLOW NEWTOWN
WEALTHY
YELLOW TRANSPARENT
RHODE ISLAND GREENING
NORTHERN SPY
GRAVENSTEIN
OLDENBURG (DUCHESS)
GANO
ARKANSAS (BLACK TWIG)
GOLDEN DELICIOUS
BLACK BEN
ESOPUS SPITZENBURG
WAGENER
STARK
KING DAVID
AGE OF TREES
Under 9 years
9-18 years
19 years and over
U.S. DEPARTMENT OF AGRICULTURE
NEG 21572 BUREAU OF AGRICULTURAL ECONOMICS

FIG. 3.

the North Central states Oldenburg was first and Transparent second, and in California Red Astrachan was reported as in greatest demand with Red June second and Transparent third.

In the national picture McIntosh was the most popular as a mid-season variety. Wealthy was second, followed by Cortland and Maiden Blush. In the Southern States Maiden Blush ranked first, followed by Wealthy, Bonum, and McIntosh. In the North Central states Wealthy was first followed by McIntosh, Cortland, and Maiden Blush.

Considering the country as a whole, Delicious, as a late variety, led all others by far. It was followed in order by Jonathan, Stayman Winesap, Golden Delicious, Rome Beauty, Grimes Golden, Baldwin, Northern Spy, Winesap, and York Imperial. Regionally the picture is somewhat different although Delicious is first in all except the North Central states where Northwestern Greening led.

This résumé indicates a definite trend toward varieties of better quality and toward apples of the dessert type.

Small fruits. Small fruits, exclusive of grapes, contribute only a small percentage to the total production of fruits in the United States. In 1929 the amount was about 10 per cent, of which strawberries were roughly 55 per cent of the total. There are no well-defined small fruit regions in the country. In general the small fruit areas are centered about heavily populated regions such as the Atlantic Seaboard from New York south to Virginia, in the vicinity of Chicago and the west shore of Michigan, and along the Pacific Coast from Washington to California. Scattered plantings of small fruits, particularly strawberries, are to be found throughout the South Central states. It is from this region that the early shipments come to the Northern markets. Then, as the season progresses, the areas close to the large northern markets are able to supply the local demand and a few are shipped back to the Southern markets. Thus the supply of small fruits is almost continuous from early January to late August. The following maps indicate the concentrated small fruit areas of the United States. (Fig. 4.)

Since 1900 the general trend in small fruits has been slightly upward. According to the twelfth Census (1899) about 309,000 acres were devoted to the culture of small fruits in the United States. The total yield from this acreage was approximately 463,000,000 quarts. In 1909 the total acreage had decreased to 270,000 acres and in 1919 still further to 249,000 acres. In 1929, however, the total

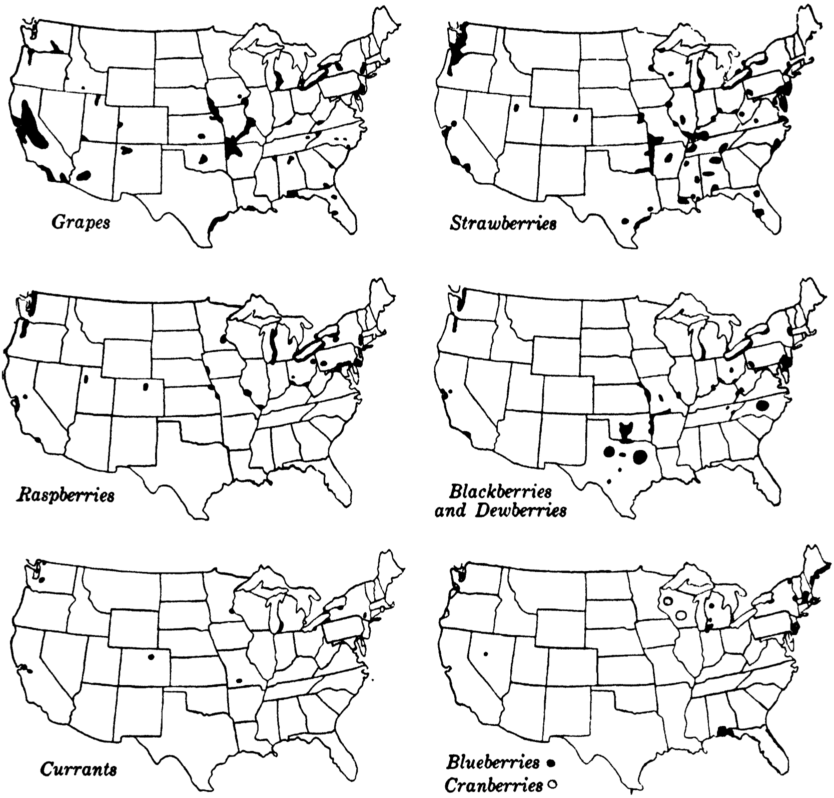

Grapes
Strawberries
Raspberries
Blackberries and Dewberries
Currants
Blueberries ●
Cranberries ○

FIG. 4. Maps of grape and small fruit production in the United States.

acreage had reached 386,664 acres with a corresponding increase in the production of all fruits with the exception of blackberries which has declined steadily since 1899. In 1936 the total money value was placed at $63,810,720. (Tables 3, 4, 5.)

TABLE 3. STRAWBERRY ACREAGE BY DIVISIONS, 1909, 1919, 1929*

Division	*1909*	*1919*	*1929*
New England	4,432	3,353	3,600
Middle Atlantic	19,202	13,909	12,767
East North Central	23,604	24,258	27,549
West North Central	16,433	18,147	36,851
South Atlantic	37,280	18,058	42,103
East South Central	14,253	16,038	32,865
West South Central	13,917	13,136	58,570
Mountain	3,115	1,623	3,580
Pacific	10,809	10,873	29,944
United States	143,045	119,395	242,829

*United States Census 1910, 1920, 1930.

TABLE 4. RASPBERRY ACREAGE BY DIVISIONS, 1919, 1929*

Division	*1919*	*1929*
New England	1,579	1,293
Middle Atlantic	14,375	11,884
East North Central	18,829	19,110
West North Central	6,764	6,919
South Atlantic	2,343	2,982
East South Central	821	876
West South Central	268	486
Mountain	1,560	2,586
Pacific	3,379	10,597
United States	50,278	56,715

TABLE 5. BLACKBERRY AND DEWBERRY ACREAGE BY DIVISIONS, 1909, 1919, 1929*

Division	*1909*	*1919*	*1929*
New England	690	1,010	499
Middle Atlantic	7,518	5,306	3,959
East North Central	10,655	9,301	5,349
West North Central	4,516	7,891	4,210
South Atlantic	5,423	4,638	6,620
East South Central	3,766	3,954	4,702
West South Central	5,106	9,188	13,042
Mountain	554	378	439
Pacific	3,776	4,499	5,075
United States	49,004	46,165	43,895

The export situation. When the fruit industry speaks of the "export situation" it is referring to the problem of selling a portion of the fruit crop to other countries. According to the 1935 Agricultural Census, apples rank third in volume of unmanufactured agricultural exports, being exceeded only by raw cotton and wheat. The total apple exports from the United States amount to almost half of the combined total for other fruits, exclusive of citrus, yet in 1930 the export of apples was 40 per cent greater than in 1935–36. Several factors have contributed to this decrease in apple exports. The volume of apples exported is determined by the size of the United States crop, the relative demand for apples in this country, and, in the importing countries, foreign production, and trade barriers. Prior to discussing these points, a brief review of the history of apple exports should be helpful.[8] Apples were exported from the United States almost as soon as the government itself was founded, but it was not until the middle of the 19th Century that exports exceeded 300,000 bushels. From this point on apple exports increased sharply, and by 1880 they had exceeded the three million mark. Continuing from that

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**Ibid.*

point they had reached 6,000,000 bushels at the turn of the century. From 1900 the upward trend continued until the World War interrupted, but increased again sharply in the early Twenties as a result of the all-water route to Europe from the Pacific Coast states, and because of the increased production of apples in that area, and the increase in European consumption of apples. (Fig. 5.) The peak in the export trade in apples was reached during the 1926–27 season when about 21,300,000 bushels, or about 17 per cent of the commercial crop, was shipped abroad.[6,9] In 1938 we exported 12 million bushels or 15 per cent.

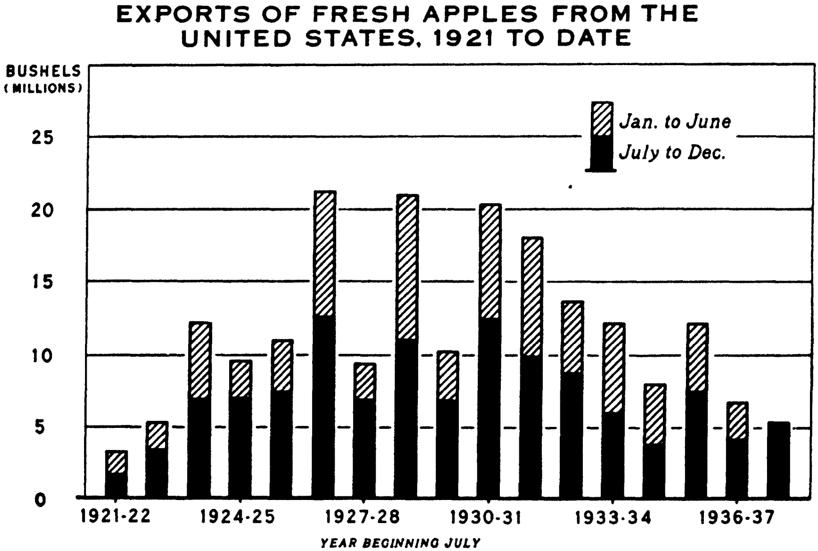

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FIG. 5.

Export of other fruits. The export of other fruits from this country, namely, pears, peaches, plums, grapes (raisins), and citrus is not in danger of extinction; on the contrary, with the exception of raisins, they are remaining at a uniform level. In fact, the citrus exports, particularly grapefruit and grapefruit by-products, have been steadily increasing since 1928.

World Fruit Production[4]

The world production of fruit, considered as a whole, compares favorably with the staple agricultural crops of the world. The world fruit production reported from countries for which estimates are available averaged 66 million tons in a three-year period from 1933–36. Fruit was surpassed by only three staple crops: corn, 122 million; wheat, 109 million; and oats, 70 million tons. Such important staples as cotton, barley, potatoes, tobacco, and wool were all under the fruit-production figure.

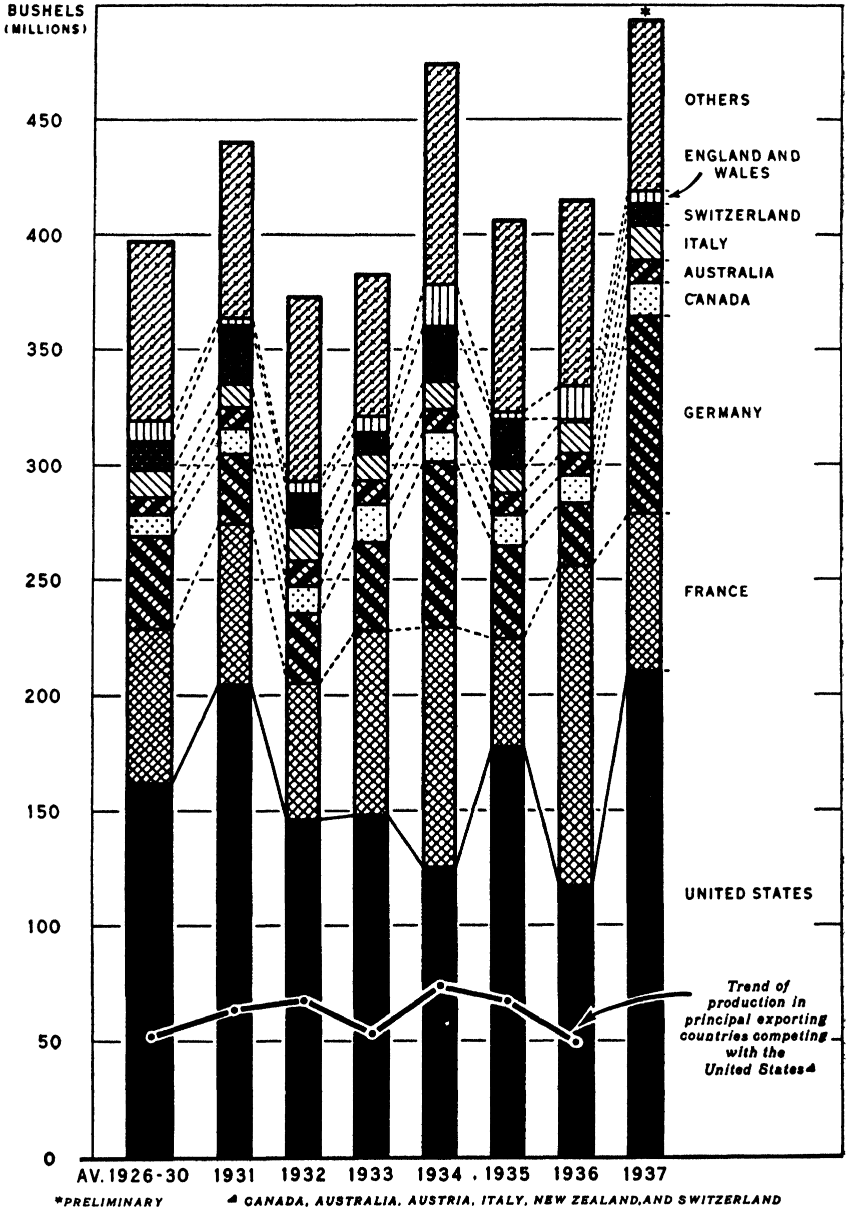
Wine grapes led the field in production of individual fruits with an average of 30 million tons or 46 per cent of the total world fruit crop during the 5-year period from 1933–37. Apples comprised 13 per cent; oranges, 10 per cent; pears, 5 per cent; plums, 4.5 per cent; bananas, 3 per cent; and all others, 20 per cent.[4] The trend of production of 14 principal fruits; namely, apples, oranges, pears, plums, bananas, table grapes, peaches, grapefruit, lemons, cherries, apricots, limes, currants, and quinces is upward.

The most important and probably the most widely grown tree fruit in the world is apples, and they are exceeded in production only by grapes. Their adaptation to the Temperate Zones has been a major factor contributing to their large production.

Dessert and cooking, cider and crab apples form the two distinct groups into which apples may be segregated. Dessert and cooking apples comprise the bulk of the production in most countries including the United States. However, in some European countries, particularly Germany, France, and the United Kingdom, the large part of the crop consists of cider varieties too astringent for raw consumption. Crab apples, while they are grown in widespread areas, do not enter into the commercial channels to any appreciable extent. They are used instead in home consumption in the form of pickles and jellies. Apples are marketed as fresh, dried, and canned fruit and are used in making a long list of products such as vinegar, brandy, candy, pectin, cider, and jelly.

The total apple production according to reports from 31 countries averaged, in a 6-year period 1931–36, 416 million bushels. About one-third of this number can be accredited to the United States, the largest producer. The world crop probably exceeds 500 million bushels, if allowance is made for the crops in such important countries as China, Belgium, and the U.S.S.R. for which definite information is lacking. Apart from the United States, the most important countries are France and Germany where the bulk of the crop is consumed at home. The production of apples in the leading countries from which statistics are available is shown in Fig. 6. The trend in world production is slightly upward

APPLES: TOTAL PRODUCTION IN LEADING COUNTRIES REPORTING



*PRELIMINARY ⁴ CANADA, AUSTRALIA, AUSTRIA, ITALY, NEW ZEALAND, AND SWITZERLAND

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Fig. 6.

despite the gradual decline in production in the United States. Production in the chief exporting countries, excluding the United States, is slightly upward as shown by the bottom trend line on the chart.

Complete information relative to the number of trees is lacking for several countries, notably France. However, of the 30 countries reporting, the United States has the largest number of trees (100,054,047) and Germany with 76,649,000 trees must be accorded second place. An increase in the number of trees was reported in 1935 over 1929 by all countries except the United States and Canada, which may indicate a greater world production in the next few years, particularly since the yield per tree is increasing in many countries.[4]

The average yearly production of cherries, grapes (wine), grapefruit, and lemons is graphically portrayed in Fig. 7. The United States ranks first in the production of peaches, plums, grapefruit, and oranges; Germany is first in cherry production; while Italy is first with lemon production.

The trend in pears is somewhat downward from the standpoint of world production, although the Argentine reports a 27 per cent increase in trees under cultivation since 1932.[7] It has been estimated that the total number of pear trees in the world is about 150 millions. Plums seem to be declining slowly in much the same fashion. Peaches are undergoing both upward and downward trends within the individual countries, and the net result just about holds the average annual world production at an estimated 125 million bushels. Cherries, on the other hand, are showing a definite increase. The world production averaged from 1926–30 660,000 short tons, while the production from 1932–36 was 733,000 tons. The production of wine grapes has increased within the past decade to a point 10 per cent greater than it was. Increased production in France, Germany, Rumania, Algeria, Argentina, and the reëntry of the United States accounts for the 10 per cent increase. Total orange and mandarin production for the 27 countries reporting has increased rapidly from an average of 133 million boxes in the 5 years 1922–26 to 207 million boxes in the 5-year period 1933–37. The United States is accredited with some of the increase, but the principal gains have occurred in Palestine, Brazil, and the Union of South Africa, where orange production is a relatively new development. In the period of 1931–

37 grapefruit has made a phenomenal rise from approximately 15 million boxes to nearly 35 million boxes. Most of the production increase has been due to the large increase in the United States plantings. The indications are that world production will continue

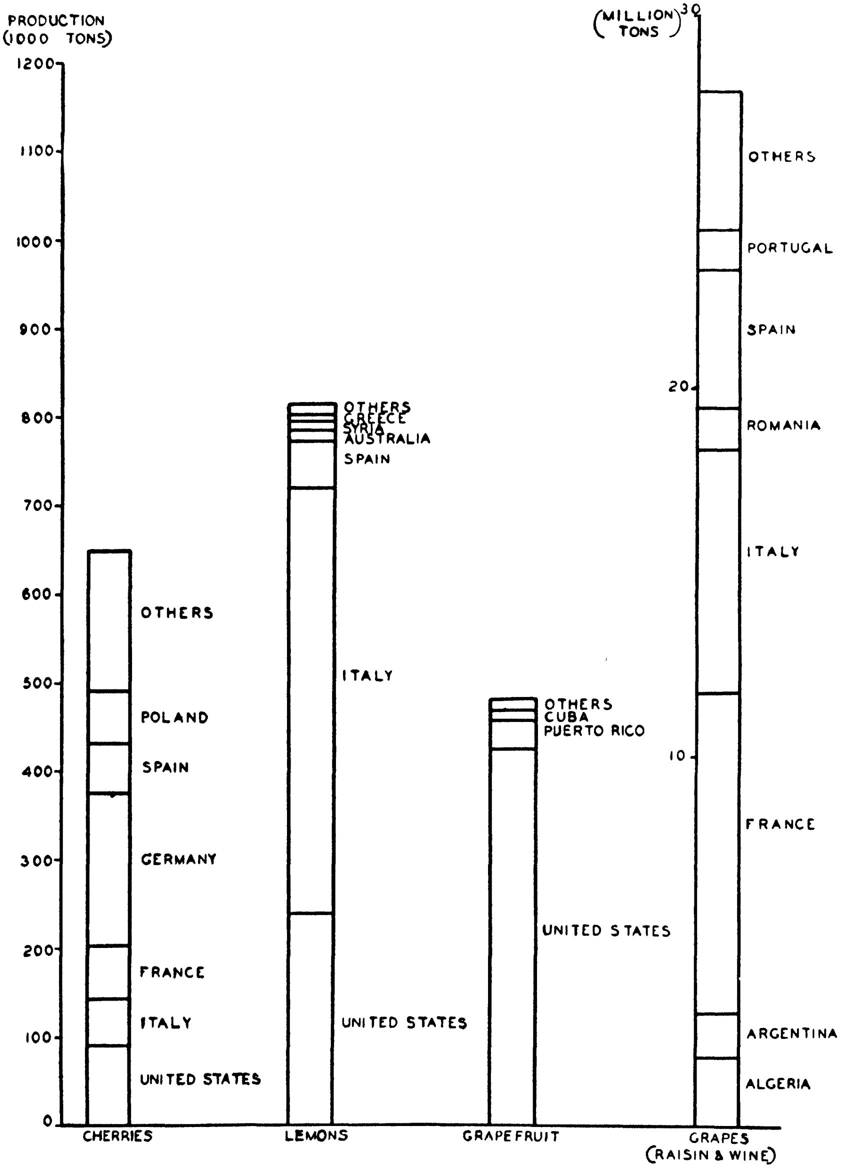

Fig. 7. World fruit production by countries computed on a 5-year average, 1926–1930.

to increase for the next 6 or 7 years. Lemons seem to be the only important citrus crop in which production increase has not been reported. In fact, the last four seasons have shown a decline from the high point of 1933, when world production was around 27 million boxes.

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2

THE FRUIT PLANT AND ITS PARTS

In viewing the fruit plant as a whole, its several morphological parts should be recognized. No matter how complicated and complex the plant may appear, it can usually be reduced to only a few regions or parts which are constant throughout higher plants. When this concept becomes clear, much confusion is at once eliminated.

Considering first a plant grown from seed, there are eight principal morphological entities to be considered, although there is a continuum or merging throughout from root tip to leaf or flower. That one part may merge imperceptibly into another, that certain parts are greatly reduced or enlarged in some species or varieties, will appear less and less as an obstacle in one's thinking as the study is pursued. These parts are: root, hypocotyl, stem, bud, leaf, flower, fruit, and seed. While they will be treated briefly at this point, there will be occasion to refer to them more in detail elsewhere.

Roots. A primary root is that morphological part of the plant which originates at the lower terminus of the hypocotyl or embryo axis and typically descends vertically into the soil possessing neither nodes nor internodes nor bearing directly leaves or flowers. The lateral branches of the primary axis are termed secondary roots. Adventitious roots are those arising from stem, leaf, or other parts than roots. Roots serve the various functions of anchorage, support, absorption, conduction, storage, sometimes as organs of vegetative propagation, and even for nutritional functions in special cases.

Anatomically, roots can be distinguished from stems in that the primary xylem is exarch and there is a radial arrangement of the vascular tissue. In older roots the arrangement of xylem and phloem is the same as in stems, i.e., collateral. In contrast to stems, the roots of the higher dicotyledonous plants do not usually possess a pith. Furthermore, roots possess a root-cap which is replaced progressively as the structure elongates. Stems are furnished with no comparable structure.

It is well known by gardeners that plants with a well-developed tap root and few laterals are difficult to transplant. Nut trees are familiar subjects of this type.

When seedling trees form the understock on which the bud or cion of the variety is worked, the primary or tap root provides the short axis from which the laterals develop. When such trees are dug from the nursery the tap root is cut and ceases to be of prime importance and is replaced by the laterals or secondary roots. This is true with the apple, pear, plum, peach, cherry, and others. In root grafting, the primary root of the seedling may be cut into two or three pieces for working, or large laterals may also be used.

Stem. The stem of a plant is distinguished from the root in several particulars, but principally by the fact that the former possesses nodes, which are geometrically arranged, and usually visible internodes. It is at the nodes that leaves occur, and commonly one or more buds are formed in the axil of each leaf. A typical stem is an ascending axis but this is not always true. There are many plants which possess horizontal under- or above-ground stems. After considerable growth has taken place, the nodes may become obscured, and other evidences must be sought. Each of the nodes, or a node and the internode above taken as a unit, is often referred to as a phytomer.

The following terms are used in this text in referring to the various stem portions of a fruit tree: trunk, branch, shoot, twig, and spur. By trunk is meant the main axis of the tree from the ground level to the point of branching. A branch is a unit or portion of the tree, and is usually spoken of as such when it also possesses lateral growths such as shoots, twigs, or spurs. An axis of the new growth which bears leaves is called a shoot in contradistinction to a similar unit during the dormant period when it is termed a twig.

Growth of the current season of a grape vine is also called a shoot, after the leaves fall it is termed a cane, while the main divisions of the trunk are called *arms.* Secondary shoots from the arms are spoken of as laterals.

In the case of the strawberry the procumbent shoots are called *runners.* The shoots or suckers which arise from an underground stem or a root (as in the red raspberry) are termed *turions.* A stolon is a stem which runs along the ground rooting at the nodes, or bends over and takes root at the tip (as in the black-cap raspberry). If a stem is bent down artificially in order to have it take root at the nodes for purposes of propagation, it is called a layer.

Since fruit spurs are of prominence in dealing with fruit trees they are given a fuller discussion.

Fruit spurs. The most casual observation of fruit trees will disclose the fact that more than one type of shoot develops. While all shoots or branches are *vegetative* in the broad sense, yet in the economy of the tree some manifestly serve for the growth extension of the branches and others are largely involved in flower and fruit production. A static view of these differential functions should not be accepted, however, for the behavior of the branch may be, and often is, reversed. The term "fruit spur" is commonly used in horticultural literature to designate a shoot or twig of limited growth with very short internodes, which during the growing season bears a cluster of leaves at the apex. It is lateral on another branch and characteristically produces flowers and fruit. No clear-cut distinction can be drawn between shoots and spurs since a fruit spur may become highly vegetative and develop into a large branch even after it has been fruiting for several years. Likewise a short growth or spur may continue growth for many years without producing flowers. (Fig. 8.) The general term spur (or shoot of limited growth)

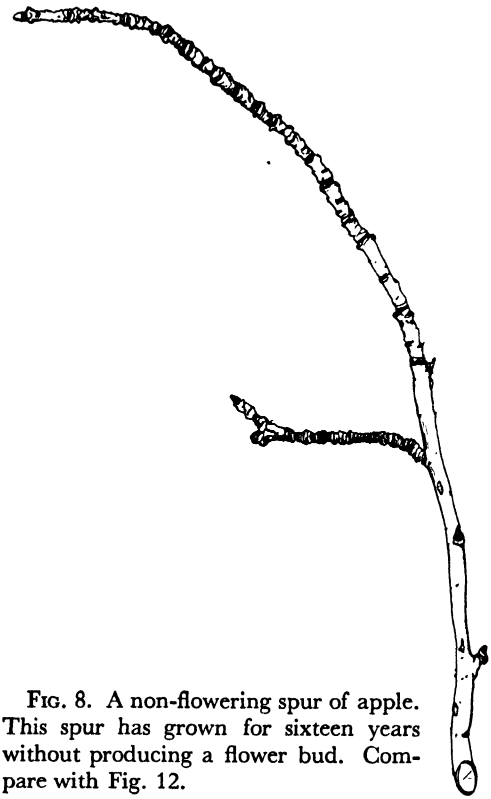


FIG. 8. A non-flowering spur of apple. This spur has grown for sixteen years without producing a flower bud. Compare with Fig. 12.

is of service to distinguish those short growths which are common on fruit trees and upon which much of the fruit is borne. In the case of spurs on the plum, cherry, and the peach, the flower buds are borne laterally, whereas the terminal bud is generally a leaf bud, and the elongation of the spur is continued in a straight line, or sometimes the spur perishes entirely after fruiting. With the apple and the pear, on the other hand, a terminal flower bud is frequently formed, whether the axis bearing it is long or short, so that further elongation of the spur is forced out of a straight line. Lateral branches may be produced below the flower bud but as a rule they are developed from axillary leaf buds, which have their origins within the flower bud itself. Such growths may be quite short or several inches long.

This secondary growth is of prime importance in the maintenance of the fruit spur, although when the spur is very weak it may not develop. The potentiality of continuing growth or development in the short spur, especially after it becomes old, is centered largely in the terminal bud, whether this is a leaf or flower bud.

The special type of spur or spurs found in each fruit will be referred to in the treatments below.

Buds. A study of buds and the bud systems of fruiting plants is of importance to both the student and the practical horticulturist. An acquaintance with the kind of buds and their location has its bearing on intelligent pruning. A more intimate knowledge of the form, color, size of buds, and the angle they make with the stem may be used as a means of identifying fruit varieties in the dormant season and for other taxonomic purposes.

The consideration of buds naturally divides itself into three phases: (1) the location of the buds on the tree, and the *bud system* in the different kinds of fruits; (2) the time and details of differentiation of the flower buds; and (3) the factors that influence the formation of flower buds.

Although the study of the location of the buds on the tree is not a matter of intricate research, yet it requires accurate observation, for there is much for the individual to learn through personal investigation if he is to be well equipped in this phase of horticulture. Buds in different locations on spurs or twigs vary in hardiness both in winter and after growth starts in the spring. Doubtless more is to be learned in this and related fields regarding buds.

Buds defined. A bud may be defined as an incipient or unelongated branch or the free extremity of a branch. It need not be a resting stage but simply represents the tip of an elongating shoot. It may either be an unelongated leafy or flower shoot or both, and it may or may not possess bud scales. That a bud is a unit or branch initial may be noted in the practice of budding wherein a bud is inserted under the bark of another plant and the resulting branch reproduces the sort desired.

Structure of buds. As already indicated, a bud consists of a very short axis on which are borne leaves or flowers and bracts, or both, and within the axils of the embryonic leaves are found axillary buds from which the expanded shoot may branch (apple). As in all other plant parts, there is a wide range both of bud types and in arrangement of buds on the stem.

A bud may have its outer whorls or series of leaves specialized as scales or it may lack them. Most buds of northern climates have such bud scales as may be noted in the apple and elm, but a number do not possess them and no purposeful or essential character need be assigned to them. Naked buds are seen in kalmia, most herbs, black locust, carnations, etc. Bracts may replace scales in the bud structure as is conspicuous in chrysanthemum and other *Compositae;* or the sepals may serve the same purpose as is seen in the carnation, the rose, and tomato. Some bud scales are viscid as in the horse-chestnut, or possess glandular hairs as in the black currant, or are covered with a wooly pubescence as in the buckeye.

From the time the buds are initiated in the summer (or autumn) until they open the following spring, there is development whenever the temperature is approximately 40°F. or above. Some activity may go on even during the milder weather of winter. Frequently the exact number of leaves which a shoot will bear is present in the bud, but this is not always the case. However, an increased length of shoots may be due to an elongation of the internodes, such as occurs when a tree is stimulated just previous to or during growth, or if the tree is shaded during the period of growth.

Classification of buds. Buds and bud systems may be classified in several different ways depending upon the viewpoint. A terminology that is self-explanatory is desirable. Position and arrangement of buds, kinds of buds, and spurs and shoots bearing them are all involved.

Leaf buds are those in which the axis bears unexpanded leaves, together with the primordia of buds in their axils and at the apex of the unelongated axis. The leaves of fruit trees are conduplicate within the bud. If one will imagine a leafy shoot of the apple telescoped and reduced until it is less than a quarter of an inch in length and surrounded by scales, he will have a fair picture of a leaf bud of this tree. From such a bud, only a leafy shoot can arise. It may make a very short growth or a long one, but this is only a matter of degree and not of kind.

The terms "branch bud" and "wood bud" have been applied to leaf buds but since a flowering shoot is also a "branch," and the axis becomes woody, these terms are not as descriptive as "leaf bud."

Flower Buds are those within which are unexpanded flowers or both flowers and leaves. When only flowers (one or more) or only leaves occur within a bud, it is termed a *simple bud* but if both leaves and flower buds occur within one bud they are termed *mixed buds.* Examples of simple flower buds borne laterally are found in the peach, plum, cherry, almond, and apricot among tree fruits, and many cases amongst small fruits (currant, gooseberry) and ornamental plants. The loquat and mango have simple buds borne terminally. Terminal mixed buds are characteristic of the apple, pear, quince, walnut (carpellate), and of many ornamental plants and trees. Mixed buds borne laterally are found in the apple, pear, grape, filbert, and blackberry. There are two types of mixed buds. In the one case, a flower or flower cluster is borne terminally on the axis as those mentioned above; and in the other, one or more flowers are borne in the axils of the individual leaves as in the mulberry, persimmon, and Tartarian honeysuckle. Horticulturists often refer to the flower-bearing buds as *fruit buds.* This implication is somewhat misleading since many such flowers fail to produce fruits, yet it is well established in the literature and provides a convenient distinction from leaf buds. The individual flower within a bud must be referred to as a flower bud.

In the grape a group of three buds is often formed within one large bud or "eye." This is termed a compound bud. The central one forms the main branch or cane and the two lateral or secondary ones are small and usually fall soon after growth starts. If, however, the primary bud is killed by frost or other cause a secondary bud usually grows and may bear a partial crop.

Terminal and lateral buds. With buds, like leaves, there is an orderly arrangement on the stem. This capacity for precise symmetry of arrangement of parts is one of the fundamental characteristics of protoplasm. All buds on a shoot of necessity must be borne either terminally or laterally. The latter regularly occur within the axil of a leaf and are termed *axillary buds*, although at times some lateral buds are adventitious (rare). If more than one leaf-scar is found at the base of a bud, it must be considered terminal though on an exceedingly short growth, and not an axillary bud. Frequently, a very close examination is necessary to distinguish between an axillary and a terminal bud on an exceedingly short spur. On the other hand, not all buds which appear to terminate a shoot or branch are terminal, for, as in the case of many plums and the apricot, no true terminal bud is formed but the distal bud is axillary. In some plants what appear to be lateral inflorescences are terminal in origin. This is true in the grape, geranium, and tomato.

Collateral and cluster buds. Buds may depart from these two simple situations in their arrangement. If two or more buds occur side by side at a node, they are said to be collateral (or supernumerary) as in the peach, some kinds of plums, currant, and gooseberry. Or if they are located one above another, they are "superposed," as in the locust, Dutchman's Pipe, yellow wood. In the Irish potato buds occur so close together at a node or "eye" that they are termed *cluster buds.* In the plum, particularly varieties of *Prunus salicina*, the internodes on spurs are so short as to give the effect of a cluster of buds.

The Differentiation of Flower Buds

Before studying the factors that influence the formation of flower buds in fruit trees, the morphological changes which take place in bud formation from the earliest stages to completion should be reviewed. This has been worked out for several of the fruits, and descriptions of the stages of development are available for the apple, pear, peach, plum, cherry, loquat, grape, strawberry, and others.

It has long been recognized that in deciduous tree fruits, generally, the flower buds are more or less well developed the season previous to their unfolding, although the details of their formation have been worked out more recently. As late as 1899 Goff wrote, "no systematic investigation seems to have before been made that gives us any definite knowledge as to the time when the development of the flowers actually begins, the rate at which it progresses, or the period through which it continues in any of our fruit-bearing plants." [7]

The apple. The broader details of the differentiation and development of the various floral structures and organs have been carefully outlined by Kraus and Ralston for the apple.[10] The course of development is similar for the pear, and is broadly the same for drupaceous tree fruits, except that in the latter, the receptacle, or shuck or calyx-cup as it is sometimes called, and the carpel or carpels, are not united during development as they are in the pomaceous types. The apple, therefore, may well serve as a basis for following out the sequence of developmental changes which take place in the differentiation of the flower buds and floral parts in the more common deciduous tree fruits.

Just prior to differentiation of the parts of the flower bud, it is not possible to distinguish between those growing points from which flower primordia will be developed and those which will remain as "vegetative" growing points. Each shows a smooth rounded crown of meristematic tissue more or less enclosed by the beginnings of leaves or bud scales. As the season progresses, the axis from which a flower bud will develop gradually becomes distinguishable through what appears to be a thickening or more broadly rounding or flattening-out of the growing apex or the crown (growing point), and soon thereafter the contour of this crown becomes slightly irregular or papillated, due to several new growing points becoming organized, which now proceed to develop into new axes (the individual flower primordia) and on these in turn growing points give rise to the individual floral parts and tissues. The development of the floral organs is acropetal, which means that they are differentiated in the same sequences as they occur in the fully developed flower. Thus their order of development is as follows: calyx (sepals), corolla (petals), stamens and pistils (carpels). As the pistils develop, the ovarian cavity is formed and upon the placentae of the latter the ovules are borne. (Fig. 9.) Much of the same type of flower-bud development occurs in the loquat.[14]

The exact time of initiation of flower buds in the apple varies somewhat with location and variety. Drinkard,[4] working with Duchess of Oldenburg in Virginia, noted that primordia of flower buds appeared June 15–30; calyx lobes, June 30—July 7; anther primordia, July 7–14; pistil appeared August 7–14; cavities of ovary, September 15–30; petals from base of calyx, November 15; during winter the flower was in the pollen mother-cell stage; ovules did not appear until March; tetrad formation began in March and there was mature pollen one week later; and differentiation was complete by April 1.

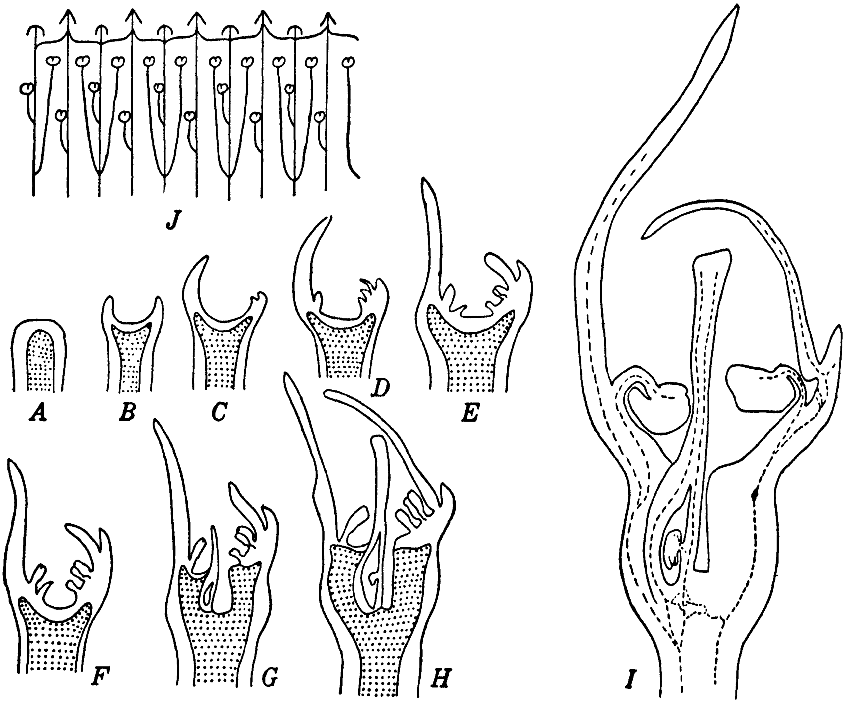


Fig. 9. *A–H*, stages in the development of the flower of the apple showing epigyny. The stippled regions indicate the pith of the axis. *I*, a young flower bud showing epigynous character and vascular system. *J*, diagrammatic representation of the vascular system of the apple. (From Hayward, *The Structure of Economic Plants*. Redrawn and adapted from Kraus.)

Other tree fruits. Tufts and Morrow [16] working in California recorded the following times when differentiation was first observed in various fruits. Almond, late August to early September; apple, mid-June; apricot, early August; sour cherry, early July; sweet cherry, late June to early July; peach, late July; pear, late June to early July; plums, late July to early August. Outline drawings of longitudinal sections through Royal apricot flower buds showing their progressive development are shown in Fig. 10.

Barnard and Read[2], observing these phenomena in Victoria, Australia, noted that in the cases of the pear, plum and prune, and apricot and peach there is a close correlation between the cessation of shoot growth and blossom initiation. This is, in general, true elsewhere.

Barnard[1] records that in apples the flower buds are formed during late December and early January (for Victoria, South Australia, Western Australia, and Tasmania), and in the stone fruits somewhat later.

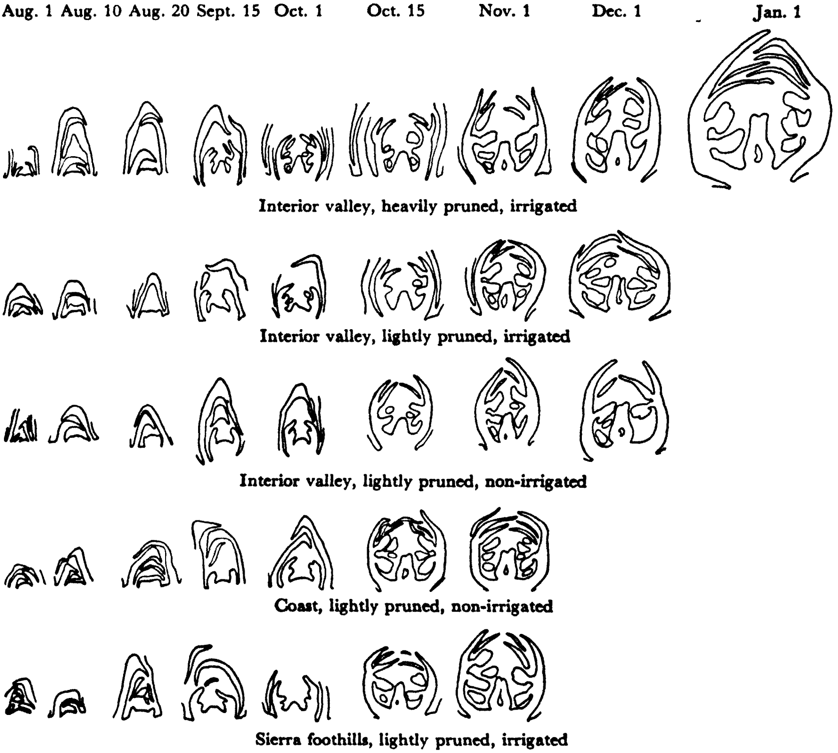

Aug. 1
Aug. 10
Aug. 20
Sept. 15
Oct. 1
Oct. 15
Nov. 1
Dec. 1
Jan. 1
Interior valley, heavily pruned, irrigated
Interior valley, lightly pruned, irrigated
Interior valley, lightly pruned, non-irrigated
Coast, lightly pruned, non-irrigated
Sierra foothills, lightly pruned, irrigated

FIG. 10. Seasonal development of Royal apricot flower buds in 1922–23 as influenced by conditions indicated.

The strawberry. Goff[7] and a number of other investigators[8, 17, 18] have studied the time of flower initiation in the strawberry and all agree that the principal time is in September although there is a slight variation in varieties and in location. In the case of everbearing varieties, as discussed elsewhere, flower buds are differentiated more or less throughout the growing season, except in early spring. In the southeast differentiation occurs both in the fall and spring and in Florida throughout the winter also.

It has also been discovered that there is a difference in the rate of development of the buds following differentiation. "In the strawberry there are many varieties which differentiate their fruit buds early, develop rapidly, and are among the first to bloom and first to ripen their fruit." The converse of this is also true, with other varieties. "Thus in Maryland, the Excelsior reached the same stage of development in 48 days from time of definite fruit-bud differentiation as did the Howard 17 (Premier) in 67 days." [17]

Red raspberries. MacDaniels [11] in New York found that in the Herbert variety the formation of flower buds took place between September 6 and January 11. In Maryland the differentiation occurred from early October to December. Flower buds were initiated somewhat earlier in the Lloyd George and White Queen than in Ranere, Sunbeam, Chief, Latham, and Viking. In these latter ones, they could not be recognized until late November or early December.

"Investigations in Oregon have shown that fruit-bud differentiation in red raspberries is progressive from the upper portions of the cane downward. Studies during 1933 and 1934 on seven red raspberries, namely, Cuthbert, Lloyd George, Chief, Latham, Ranere, Newburgh, and Viking showed that fruit buds were already well differentiated in the upper portions of the canes before September 15 in all these varieties. At distances of less than 40 inches above the ground there were great differences in the time of fruit-bud differentiation. It was found in the Lloyd George that fruit buds had differentiated in all portions of the cane before September 15. At distances of 20 to 40 inches from the base, fruit-bud differentiation occurred in the Cuthbert from November 3 to January 7; in the Viking, from September 15 to November 3; and much later, probably after March 7, in the Newburgh. The lower 20 inches of the canes showed no definite fruit-bud differentiation up to March 8 in the Chief, Latham, Ranere, and Newburgh varieties, while in the Cuthbert, it was found taking place from November 3 to January 7, and in the Viking between November 6 and March 9." [18]

Black and purple raspberries. MacDaniels found the first evidence of flower-bud differentiation in Cumberland black raspberry on

October 6. Approximately the same time was found in Maryland for Cumberland, and Black Giant raspberries, and Potomac purple raspberry.

Dewberries and trailing blackberries. Work by the United States Department of Agriculture in Oregon has shown that flower-bud differentiation begins in most portions of the loganberry canes at least by the middle of September. Similar developments were found in the Youngberry, while in the Lucretia and Austin Thornless it probably begins a little earlier.

Studies in the trailing blackberries showed definite flower-bud differentiation in early December in Maryland and during the month of November in Oregon. The Himalaya blackberry did not show definite evidences until January in Maryland and the earliest date under Oregon conditions was January 30. The Brainerd, which is a cross between an eastern upright blackberry and Himalaya, showed definite differentiation in Maryland in November and during the same period in Oregon.

Other small fruits. MacDaniels has found that Houghton gooseberry showed differentiation of flower buds beginning on August 16, and that it had taken place prior to that time in the Cherry red currant.

Fruiting Habits of Different Species

Fruiting of the apple. In the apple, flower buds are formed both terminally and laterally, although the former situation is more characteristic. Short or long spurs (depending partly upon variety and partly upon the nutritional condition of the plant) are formed from lateral leaf buds on twigs of 1-year's growth. These spurs may continue to form terminal leaf buds for years, that is, remain weakly vegetative (Fig. 8), or they may form a terminal flower bud the first or second year. (Fig. 11.) When a flower bud is formed, the end of the growing axis is occupied by flower primordia so that the spur or axis can no longer continue in a straight line. (Fig. 12.) Since leaf buds are found in the axils of the lower leaves of the shoot which arises from the flower bud itself, a secondary shoot (one or two) is formed which continues the growth of the spur. (Fig. 12.) Occasionally the lateral growth arises from a leaf bud below the flower bud, but in characteristic spurs the former situation prevails. (Fig. 12.) This secondary shoot (or shoots) may form a flower bud its first season but usually it grows at least two years before a flower bud (terminal) is produced. This process is continued, often for years, before the spur dies. Not infrequently what starts out to be a fruit spur becomes very vegetative and a branch develops from it which may not fruit again in the usual manner of a spur. The type of spur system formed is largely characteristic of the variety.

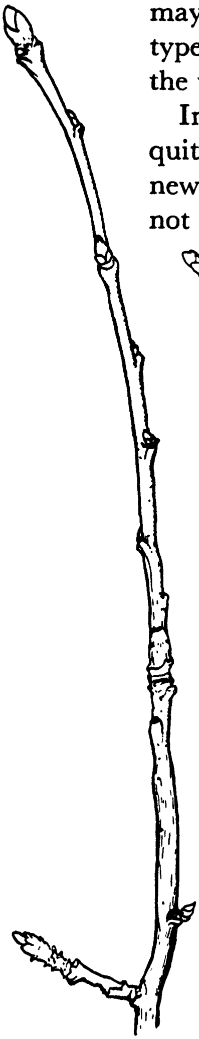


FIG. 11. *At left.* An apple spur system in which a terminal flower bud is formed and two axillary or lateral flower buds. The other buds are leaf buds.

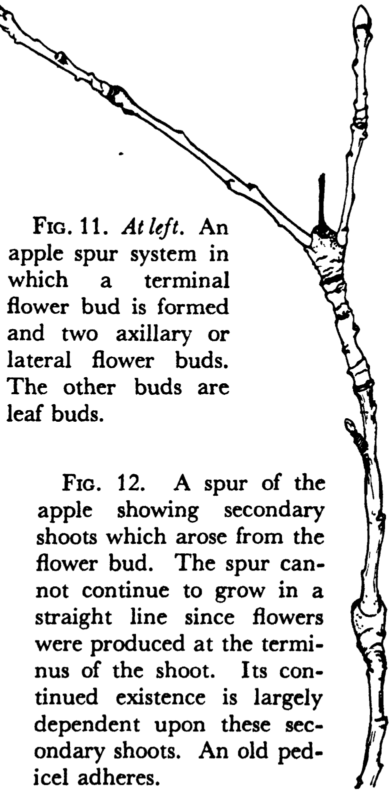
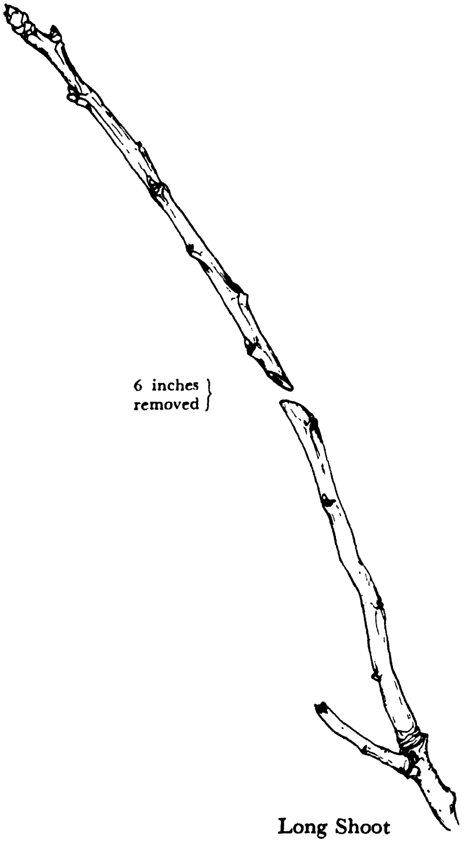


FIG. 12. A spur of the apple showing secondary shoots which arose from the flower bud. The spur cannot continue to grow in a straight line since flowers were produced at the terminus of the shoot. Its continued existence is largely dependent upon these secondary shoots. An old pedicel adheres.

In addition to flower-bud formation on spurs it is quite common for such buds to be formed laterally on new shoots. (Fig. 11.) That such buds are axillary and not found on very short spurs can be determined by observing whether there is one or more than one leaf-scar at the base. If the latter is true then the bud is terminal. The student should make close observations, however, for it is not unusual to find a very short spur on the 1-year wood, having produced only two or three leaves. Some varieties of apple yield annual crops because the fruit in one of the years is produced largely from axillary flower buds on terminal shoots. The formation of axillary buds, however, does not insure annual bearing. Such varieties as Jonathan, Wealthy, and Missouri Pippin produce axillary flower buds freely. Golden Delicious begins fruiting in this way, and, since such lateral buds are smaller and more retarded in their opening than terminal buds, the resulting apples are frequently smaller in size than is usual from terminal ones. This observation can probably



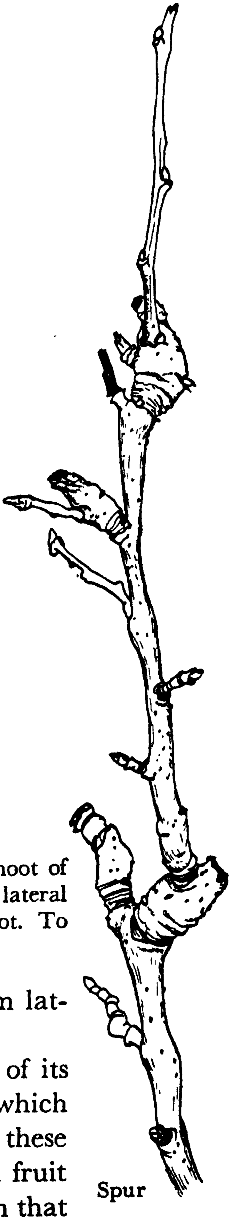


FIG. 13. A terminal flower bud is formed on a long shoot of pear. Ordinarily flowering occurs on short spurs or from lateral flower buds such as is seen near the terminus of this long shoot. To right a spur system of pear.

be made for all varieties that produce fruits from lateral buds.

The Rome Beauty produces a large number of its flower buds terminally on rather long shoots which usually bear fruit every second or third year. As these shoots elongate the scars left by the flowers and fruit are gradually overgrown which results in a stem that is nearly straight rather than crooked as in the case of a short spur system. When a Rome Beauty tree is young it grows nearly upright, but after fruit has been produced for several years, the branches become quite pendent from the weight of the fruit at the terminals, as is described elsewhere.

Fruiting of the pear. This fruit is closely related to the apple botanically, and flower buds are formed in the same positions. The flower bud is usually terminal on spurs, although terminal ones on long shoots or even on water sprouts are fairly common. (Fig. 13.) The flower buds of pear are usually large and conspicuous and frequently form a wider angle with the shoot than is common with the apple. The bud scales are often brown or yellowish in color. These characters are of some taxonomic importance.

Fruiting of the quince. This fruit differs from the apple and pear in the behavior of its over-wintering flower buds, in that a short leafy growth of from one to several inches is produced before the single flower bud unfolds. The flower buds are usually produced on short shoots which become branched somewhat after the manner of an apple spur. Axillary flower buds may also occur abundantly on 1-year-old terminal twigs. (Fig. 14.)

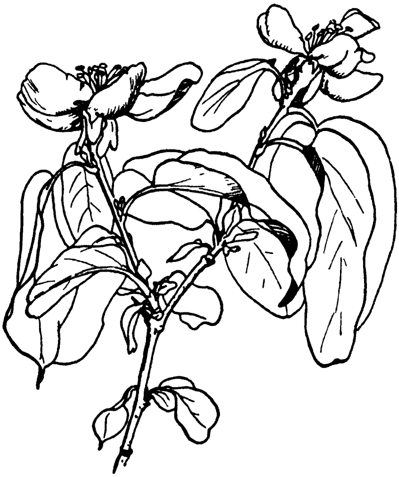


FIG. 14. The quince flowers at the terminus of a new shoot which is much longer than that found in the the apple.

Fruiting of the peach. The peach differs from the apple and pear in that flower buds occur only in the axillary position, never terminally. They develop on vigorous, often much-branched, 1-year-old wood, which also accounts for the vegetative extension of the tree. It will be remembered that 1-year-old terminal shoots of the apple yield a very small portion of the flower buds and very frequently none. The lateral shoots of 1-year-old wood of the peach may be rather short (less than 1 to 3 inches long) and because of their length may be termed spurs. Such spurs are frequently very fruitful, and the flower buds produced on them may be more hardy than those on the more rampant growth of other branches or trees. Also short spurlike growths are frequently found on the older branches or main trunk of the tree. These spurs arise from latent buds, frequently at the place where a shoot or branch has died or been removed. These spurs are often fruitful but may perish after one year's growth or they may continue a short unbranched growth from a terminal leaf bud for 2, 3, or more years, but usually they are not long lived.

The peach further differs from the apple and pear in the number of buds that may occur at a node. Any of the following conditions may be found at a node, and sometimes all of them on a single shoot:

1. A single leaf bud. L
2. An axillary flower bud. F
3. A leaf bud and a flower bud in the axil of a single leaf. LF
4. Two flower buds with a leaf bud between them or to one side of them in the axil of a single leaf or with a leaf subtending each bud, or on a very short spur. FLF or FFL
5. Two or three flower buds in the axil of a single leaf. FF or FFF
6. A flower bud between two leaf buds. LFL

This situation has been analyzed in detail by Marshall.[13] He noted that the total number of flower buds increases with the length of shoots up to 24 to 28 inches and then decreases with additional shoot length. As a rule a weak or a short branch or spur bears only single flower buds, while the collateral arrangement is of frequent occurrence on long shoots. A shoot may be so strongly vegetative, however, that no flower buds are produced. The FFF and FFLF nodal arrangements were of comparatively little consequence on any shoots. The FL type was more abundant on median portions of shoots than elsewhere while FF buds have an irregular distribution. In general, he concluded that cultural and pruning practices can be planned without much regard to flower-bud formation, fruiting habit, or winter killing of flower buds. (Fig. 15.)

Fruiting of the plum. In studying the bud systems of plums three major groups should be recognized according to species as follows: European plums, *Prunus domestica* and var. *insititia*, the Japanese varieties *P. salicina*, and the American plums *P. americana*, *P. nigra*, *P. hortulana*, *P. munsoniana*, and others. All, however, bear only simple buds, although leaf-like bracts may appear when the buds open, as is true with the cherry.

Domestica plums often develop a well-defined system of fruit spurs in which the terminal bud is a leaf bud (rarely a flower bud).

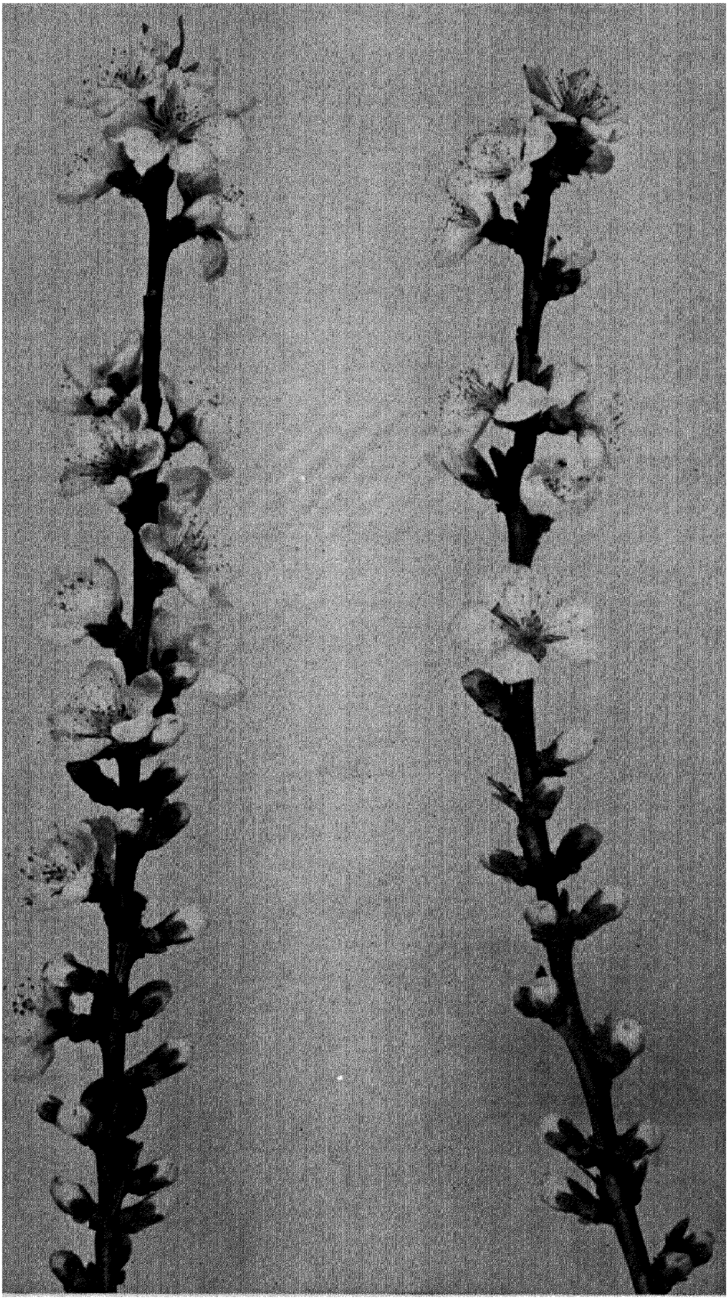


FIG. 15. Flowering of peach. Note flower buds are axillary. One or two flower buds may occur at a node and in the latter case a leaf bud occurs between them. A single flower bud and a leaf bud may also occur together.

Flower buds are axillary both on the 1-year-old terminal growth of the tree and on 1-year-old wood of the spur. They are borne singly or in practically all combinations of the collateral arrangement, *viz:* F, FL, FLF, FF, FFF, LLF.

The bud itself may contain one, two, or three individual flower buds (the number being somewhat characteristic of the variety) which may open before, with, or after the leaves appear. The spur under some conditions may terminate in a thorn rather than in a leaf bud. Occasionally the terminal leaf bud fails to develop and what appears to be a terminal bud is a flower bud, or a pair of flower buds. The variety Imperial Epineuse is characterized by an abundance of short spurs. In some seasons a variety of Domestica (e.g., Bradley's King Damson) may be so abundantly set with axillary flower buds as to give the same "snowball" appearance as is seen in Japanese varieties. In the main the Damsons are somewhat less free-flowering on the terminal shoots than many others of the *Domestica* class.

Japanese, like other plums, produce axillary flower buds only. They are borne on new wood either singly or in pairs with a leaf bud between them, or in clusters. They are also borne singly or in clusters on short spurs on the older growth, and such spurs may be produced on new growth. Spurs from latent buds on the trunk and branches of old trees are not uncommon (Maynard, Burbank, Wickson). Maynard also produces flower buds abundantly on very vigorous watersprouts. This abundant blossoming of Japanese plums makes them subjects of considerable ornamental importance.

American plums are more like Japanese than the European varieties in their fruiting habits.[3] The general contour of the trees and

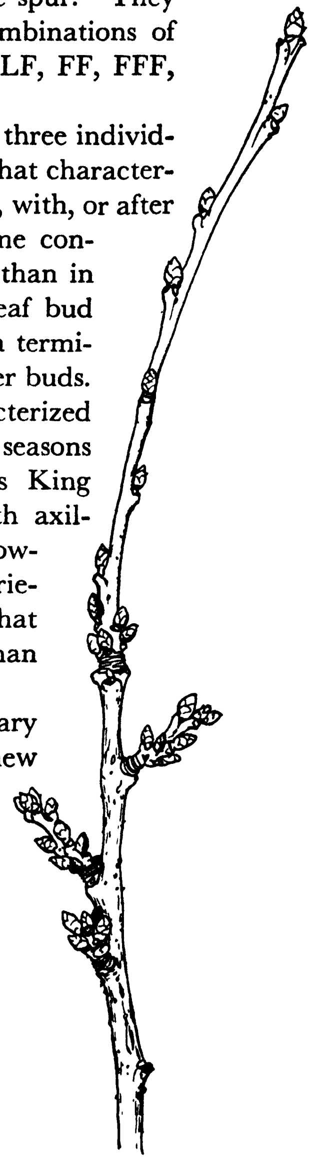


FIG. 16. A spur system of the sweet cherry. Note axillary flower buds and also flower buds on the spurs.

branches is characteristic of these species and unlike either of the other two groups. The Freestone Goose variety produces a FFF situation at the nodes with no leaf bud. Surprise is conspicuous by the free-flowering spurs as well as a large number of collateral buds at the nodes of the terminal shoots.

Fruiting of the cherry. Cherries are usually divided into three groups from a botanical and taxonomic viewpoint, *viz, Prunus avium*, the sweet cherries; *P. Cerasus*, the sour cherries; and *P. avium* × *P. Cerasus*, the Dukes. Like the other stone fruits mentioned, all of the flower buds of cherries are axillary and the terminal is a leaf bud.

In sweet cherry varieties flower buds are formed freely both on new terminal shoots and on spurs, but particularly the latter. (Fig. 16.)

The sour cherry forms its flower buds in the same positions as does the sweet cherry. (Fig. 17.) Not infrequently all of the axillary buds are flower buds, which results in a naked branch or one free of all lateral growth the following season. In other cases a number of leaf buds are formed which develop into shoots or spurs. This latter situation denotes a more vigorous condition of the tree and is more to be desired. The Montmorency variety, which is the leading one, is inclined to abundant spur production and to produce most of its fruit from these spurs. As the tree becomes older there is a greater and greater tendency toward spur rather than shoot formation. Gardner [6] shows that both Montmorency and English Morello varieties produce lateral flower buds freely on shoots up to 18 inches in length but that shoot growth 8 to 10 inches long is most satisfactory in lateral flower-bud formation. The longer the growth of any particular shoot the greater the number of lateral buds that will develop shoots but this is more pronounced in English Morello than in Montmorency. In other words, in order to secure a branch with many spurs it is necessary to keep the tree or branch vigorous so that fewer blossom buds are formed. This is brought about by cultivation, fertilization, and in some cases by pruning.

Fruiting of the apricot. The fruiting habit of the apricot is practically the same as that of the peach. Flower buds are borne singly, or in pairs on the new growth with a leaf bud between them, or on short spurs on the older growth. There is no true terminal bud, but what appears so is a true lateral bud and it continues the growth of the branch. The cluster of flower buds on the new growth is borne in the axil of a single leaf instead, as may occur at times

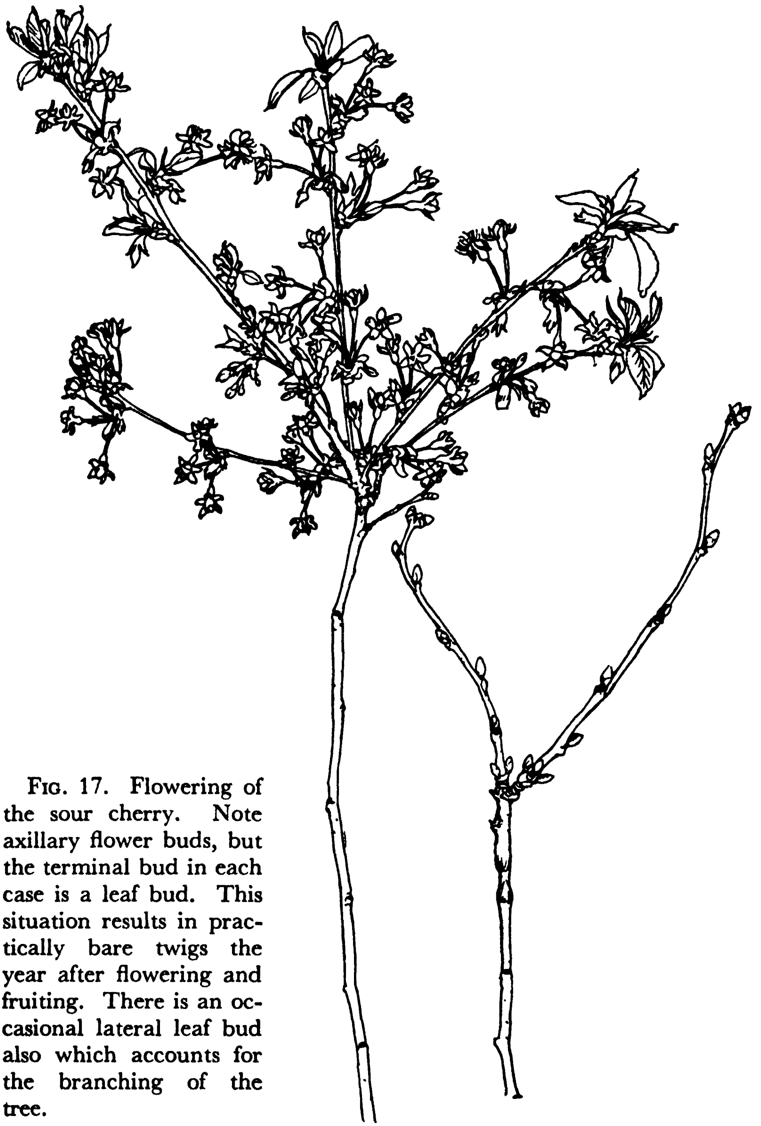


FIG. 17. Flowering of the sour cherry. Note axillary flower buds, but the terminal bud in each case is a leaf bud. This situation results in practically bare twigs the year after flowering and fruiting. There is an occasional lateral leaf bud also which accounts for the branching of the tree.

with the peach, each bud in the axil of a leaf. Spurs are formed more frequently with the apricot than with the peach.

Fruiting of the grape. The grape produces over-wintering mixed or compound buds borne laterally on canes of one year. The buds are often called "eyes" and are compound as well as mixed. That is, there are usually 2 to 5 individual buds at each node within the bud scales, and upon the initiation of growth one of the buds produces the main shoot and the laterals make only a short growth and often fall. The stronger bud which produces the shoot is referred to as the primary bud. This shoot produces three or four times as much fruit as the weaker lateral ones. (Fig. 18.)

The flower clusters are found opposite a leaf in the place of a tendril. Different species have characteristic numbers of inflorescences per shoot and their location from the base of the shoot is also characteristic. Most species average two inflorescences per shoot but *Vitis labrusca* may bear from three to six. The number of cluster primordia which are present in the bud is determined by the growing conditions of the previous season.

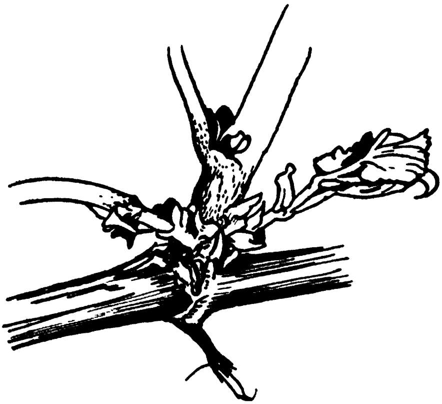


FIG. 18. The over-wintering bud of the grape is usually a compound bud. The main cane comes from the terminal bud and the two lateral ones are usually weak and fall early in the season.

Inflorescences of Fruit Plants

Flowers may be borne singly on the plant, or there may be a number of them associated together in a cluster. This arrangement of flowers on the stem or axis is termed an inflorescence. It may or may not bear leaves or bracts and it may or may not have a stalk. Morphologically it is a flower-bearing shoot; and may be determinate or indeterminate in growth. The inflorescence may terminate a shoot or it may be borne in the axil of a leaf. It does not arise directly from an internode. The branched inflorescence usually, but not always, bears bracts or modified leaves.

General Classes of Inflorescence

Since there are several kinds of inflorescences or arrangements of flowers in a cluster their classification will become clearer if the three general situations are first described.

1. *Solitary flowers.* A flower may be borne singly in the axil of a foliage leaf, at the terminus of the shoot, or from a specialized stalk in a number of herbaceous plants (as in bulbs and corms). The stalk bearing such a flower is termed a peduncle, or in the latter case a scape. (Figs. 14 and 19i.)

Examples are the quince, peach, apricot, almond.

2. *The racemose inflorescence.* In this case the axis of the flower cluster (peduncle) continues growth and new flower buds with their subtending bracts continue to be formed near the growing point thus producing a succession of new flowers. The lowest flowers, being the oldest are first to open, and the blossoming proceeds upward, that is in acropetal or centripetal succession (from circumference toward the center). This indeterminate type of inflorescence is by far the most common. It is recognized at once in such flowers as the gladiolus, hollyhock, and lily of the valley. There are various types of the racemose inflorescence.

Examples are seen in the following fruits:

(a) Raceme. Flowers are borne on pedicels which are about equal in length. Wild cherry, currant, gooseberry, blackberry, blueberry. (Fig. 19a.)

(b) Catkin or ament. A spike or raceme with a slender rachis bearing many unisexual, apetalous flowers, and which falls as a whole when the fruit is mature. Mulberry. (Fig. 19c.)

(c) Umbel. A short rachis bearing long-pedicellate flowers of about equal length, spreading umbrella-like. No common fruits. (Fig. 19f.)

(d) Corymb. The main axis is elongated and the pedicels are of unequal length in such a way that the lower ones are longest and the upper or central ones are shortest resulting in the flowers lying in a horizontal plane. As in all racemose types the lowest one (in this case the outermost flower) reaches anthesis first and the maturing of the flowers proceeds upward until the last one is at the apex or what appears to be the center. Pear (Fig. 19e.)

3. *The cymose inflorescence.* This is the converse of the racemose type of flower arrangement. At the growing point a flower bud is produced so that the flower axis cannot farther elongate. The other flower buds are produced below this point on the axis and hence are progressively younger from the tip of the axis toward the base. This gives a situation called determinate growth, and the opening of the flower is basipetal or centrifugal (from the center toward the

circumference of the cluster). The solitary flower is, in a sense, a cymose type.

There are fewer types of cymose flower arrangements than of racemose but they represent a distinct group and some important

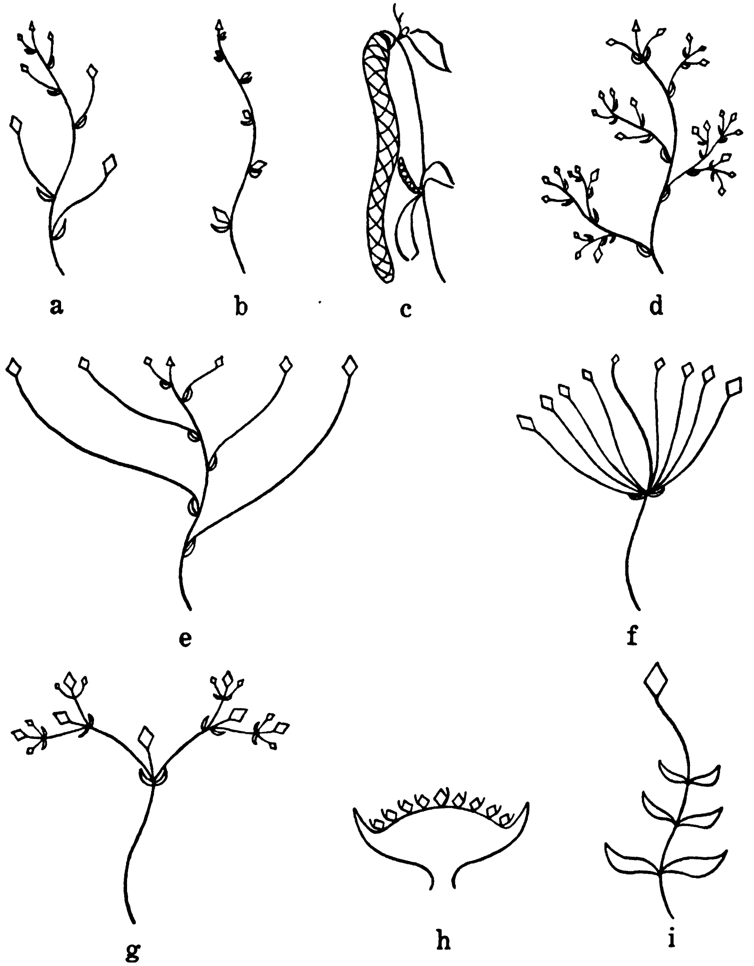


Fig. 19. Types of inflorescence. a, raceme; b, spike; c, catkin; d, panicle; e, corymb; f, umbel; g, compound cyme; h, head; i, solitary flower.

economic plants are found here. Potato, elderberry, persimmon (*Diospyros Kaki*), orange, strawberry. (Fig. 19g.)

Fascicle. A cyme with flowers closely crowded on a very short peduncle and with pedicels of about equal length. Cherry, plum.

Anomalous types of inflorescence. It is not surprising to find flower arrangments which do not fit into the conventional types. For instance in the apple and *Campanula americana* or bellwort, the terminal flower opens first which suggests a cyme, but then the basal one or ones open next and the anthesis of individual flowers then proceeds more or less upward to the apex which suggests a racemose type. These cases may be termed cymose or false cymes.

In *Vitis* the main axis is indeterminate but the secondary and ultimate axes are cymose.

The Flower Structure

A flower has been defined by morphologists as a shoot of limited growth beset with spore-bearing leaves, or "a determinate stem with appendages, and these appendages are homologous with leaves." [5] Such a definition would include many plants below the Angiosperms although we are not here concerned with them (the term "flower" as commonly used is characteristic of the Angiosperms). It is through the organs of the flower that the phenomenon of sexual reproduction takes place.

The flower parts. A *complete flower* possesses a calyx, the individual parts of which are called sepals; a corolla, the parts of which are termed petals; an androecium, composed of stamens; and the gynaecium or pistil, composed of one or more carpels. All of these parts arise from the receptacle or terminus of the shoot bearing them. These parts vary endlessly in form, color, and arrangement throughout the plant kingdom but are always found in the order named from the outer whorl inward or upward to the apex or center of the floral axis.

The calyx and corolla collectively are known as the *perianth.* The androecium and gynaecium are the spore-bearing or secondary sex organs and form the *essential organs.* All four of these parts are interpreted as specialized leaves and conform to them in their vascular arrangement and derivation from the stem (receptacle).

Not infrequently others than the petals become the conspicuous, colored, and attractive portion. These are seen in the bracts of poinsettia, and dogwood, the stamens of canna, and the calyx of tulip and crocus.

Not all flowers are *complete,* some lacking one or more of these parts, and are then termed incomplete flowers. If both stamens and pistil are present the flower is *perfect* and if one or the other is absent even though the perianth is present, the flower is *imperfect,* as in the cucumber. In the cultivated strawberry the perianth and the gynaecium are present but the androecium may or may not be present, depending both upon the variety and the environment. If present, the flower is perfect (and also complete) as in Premier and Senator Dunlap, although perfect flowering varieties vary greatly in the amount of pollen they produce, but if absent the flower is imperfect (and incomplete) as is usually true in Glen Mary and Sample and thus it is essential that a perfect flowering variety be planted with an imperfect one in order to secure a crop of fruit on the latter. It will be noted that there are no varieties of strawberry which lack the carpels.

When both stamens and pistils are present in a flower it is said to be bisexual or hermaphroditic. If carpellate and staminate flowers are borne on the same plant it is said to be moneocious, as in cucumber, melons, corn, and *Ricinus*, but if the two kinds of flowers are borne on separate plants they are dioecious, as in ginkgo, date palm, and asparagus. Some plants produce both pistillate and staminate flowers, and also bisexual ones, as maple and ash. In the Japanese persimmon (*Diospyros Kaki*) the three types of flowers are produced without any special regularity.

Relative position of the ovary. Flowers may be classified from several standpoints but because of the ultimate result in flower-bud formation, special consideration should be given to the position of the ovary in relation to the receptacle and other flower parts. This will become clear as flowers of the different classes are examined. There are four distinct types of flowers, namely, hypogynous, perigynous, semi-epigynous, and epigynous. Not all of them are clear cases since there is a gradual merging of one into the other.

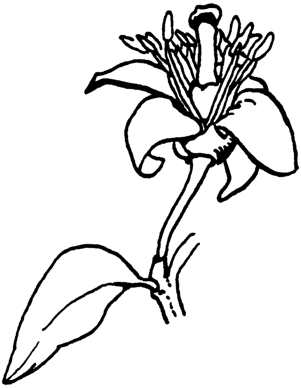


FIG. 20. Hypogynous flower of orange.

Hypogyny is a situation wherein the receptacle bears one or more separate carpels or else a syncarpous structure and the sepals, petals, and stamens arise at the base of (i.e., below) the ovary. That is, the latter three sets or organs are hypogynous, and the term is extended so as to call the entire flower hypogynous. This is the most primitive condition from the standpoint of phylogeny. In this category will be found the orange, grape, and tomato. (Fig. 20.)

Perigyny. In some flowers the receptacle is concave and the region between the stamens and base of the ovary is meristematic and a flange or cup is developed so that the stamens, petals, and sepals are borne on the rim of the receptacle disc or cup and the ovary is seated at its base. This gives the effect of their being borne around the gynaecium. Examples of perigyny are seen in the peach, plum, cherry, blackberry, strawberry, and rose. (Fig. 21.)

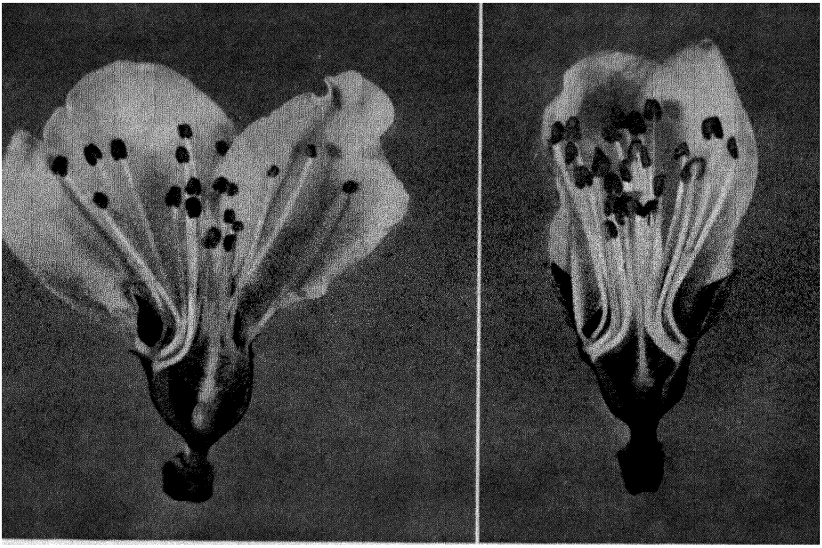


FIG. 21. Perigynous flowers of peach. Note that sepals, petals, and stamens arise from rim of receptacle. The ovary is superior.

Semi-epigyny. This term refers to a situation in which the receptacle (or inflorescence tube) is not diverged from the carpel walls for a portion of the distance from the base to the apex of the ovary. It is not literally half way but rather some portion of the distance. At the summit of the receptacle the sepals, petals, and stamens are borne, that is they diverge from the tissue of the receptacle or hypantheum, as they do in any case. This arrangement is often spoken of as perigyny, but it requires a different category if the fruit structure derived from it is to be clearly interpreted. It will be recalled that in perigyny the receptacle is free from the carpel walls throughout.

There are not many common fruits of the temperate zone which fall into this group. The better-known ones are the turban squash (Essex Hybrid), wintergreen berry, and the loquat (semitropical). The saxifrages, and *Philadelphus* flowers are also semiepigynous.

Epigyny. When the receptacle tissue entirely encloses or surrounds the ovary and is adnate or not diverged from it, the sepals, petals, and stamens arise on a level with the top of the ovary, or higher, and the arrangement is termed epigyny. There are several ways in which the epigynous condition is developed but in all cases the essential condition from the standpoint of fruit development is that the wall of the fruit consists both of carpel and receptacle tissue.

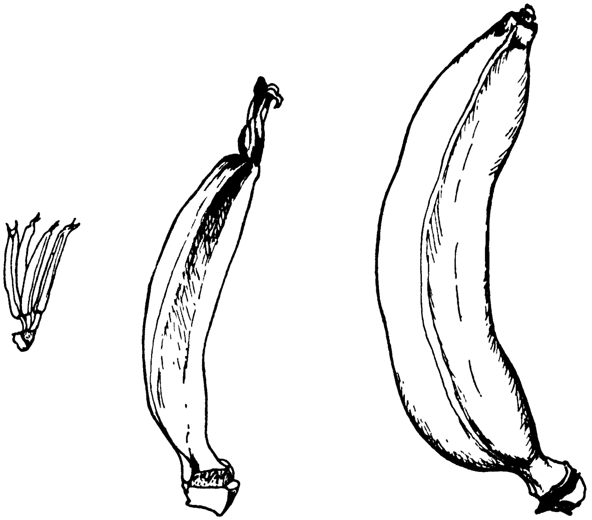


Fig. 22. The epigynous flower and the fruit of banana. Note the small ovary which becomes the edible fruit of the banana.

While most writers have considered the tissue from which the sepals, petals, and stamens obviously diverge to be hypantheum or receptacle, there are those who entirely disagree and consider this tissue to be a fleshy floral tube or the fused bases of these organs. Thus the fleshy or edible portion of an apple or the "skin" of a banana would be appendicular rather than receptacular in nature. The argument of those who interpret the tissue as a floral tube is based on the vascular anatomy of the flower. Jackson,[9] for instance, has studied a series of the Rosaceae showing various degrees of fusion of vascular bundles following fusion of the basal parts of the perianth and androecium. MacDaniels [12] likewise has compared the vascular skeleton of the apple, pear, quince, and related genera with those of other and more primitive Rosaceae. He holds that the tissue is not receptacular in nature but is the fused bases of sepals, petals, and stamens.

The subject must be considered controversial at present but the authors are inclined to the older view (also on vascular anatomy and morphological bases) that the floral organs diverge from receptacle in cases of hypogyny, perigyny, and epigyny, alike.

Familiar examples of epigynous flowers are: gooseberry, currant, blueberry, cranberry, cucumber, banana, apple, pear, quince, and pomegranate. (Fig. 22.)

The Fruit Structure

The fruit is the final product of the plant, and the seed which is produced therein is the beginning of a new plant body. Most, but not all, of the higher plants produce fruits in the course of their lives. Many fruits are edible and hence are of special interest to the horticulturist. Other fruits become decorative or showy and are grown by the florist. Still others that are intimately associated with the seed are grown by the agriculturist as "seed" (e.g., cereals).

What is a fruit? A fruit may be defined as an enlarged pistil, together with any closely associated parts. That is, a fruit has its inception in the flower. A fruit is sometimes defined as a ripened ovary, but it will be recalled that some fruits are regularly used before they are ripe (olives, cucumbers, okra, corn) and in any case the structure is a fruit before it is ripe. Not infrequently all parts of the pistil are involved in the fruit which makes the term "ovary" somewhat (although not seriously) unsatisfactory. Those fruits in which the developed carpel (or carpels) is the conspicuous portion are often termed *true* fruits, and those with associated parts as the conspicuous portion are termed *false* or *spurious* fruits.

Here, as throughout morphological studies, the student should avoid static concepts, for the play of environmental factors upon fruit development may yield unpredictable results. Furthermore, the fruit structure is, after all, a vegetative one, only the seed being the result of sexual reproduction, and even this latter statement is not always true.

But notwithstanding these aberrations some classification of fruits is desirable, some grouping of conventional forms with like characteristics.

The carpel. The carpel is interpreted by botanists as a specialized leaf structure, just as are the other floral parts.[19] In Angiosperms it is an unexpanded or somewhat tubular structure while in Gymnosperms the homologous structure is expanded or at least not "folded" into a seed envelope. On or within the carpel the ovules are borne, usually (but not always) on the edges of the organ, i.e., marginal. Since megaspores are produced within the ovules, the carpel is technically a spore-bearing leaf or megasporophyll. This definition is perhaps the most accurate one that can be given.

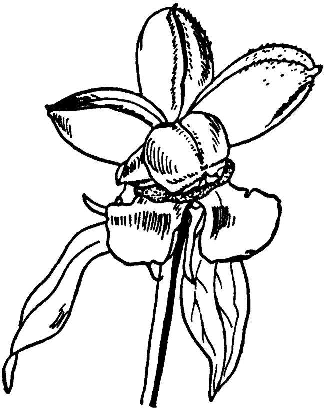


FIG. 23. Apocarpous situation in the peony.

The carpel is, therefore, the unit of structure of the pistil or gynaecium. It consists of a stigma, style, and ovary, although the style may be very short or wanting. The carpel (or group of carpels) occupies the central position in the flower. If there is only one carpel to a flower (avocado) the pistil is simple. If more than one, then it is compound. The carpels of a pistil may be diverged (separate or free) as in a peony (Fig. 23), raspberry, strawberry, clematis, rose, when they are said to be apocarpous, or they may completely or nearly completely lack divergence as in a tomato, grape, and orange, when they are termed syncarpous. Troll [15] also includes a paracarpous situation where the compound ovary is unilocular with parietal or central placentation.

Whether the flower structure exhibits hypogyny or epigyny, apocarpy or syncarpy has much to do with the ultimate fruit structure, and the fruit cannot be intelligently interpreted without first knowing the flower situation.

As indicated above, if the pistil only is represented in a fruit as in the grape, orange, persimmon, or avocado then it is termed a true fruit. But, if the flower was epigynous then the receptacle (or floral tube) is present in the fruit structure as well as the carpels, such as is seen in the banana, apple, cucumber, cranberry, and squash, and the fruit is often termed false or spurious. (Fig. 24.)

If the flower was semi-epigynous, that is the sepals, petals, and stamens diverge from the receptacle somewhere between the base and the apex of the carpels, so that a portion of the carpels is exposed (as in a turban squash), then the fruit is also false or spurious.

Kinds of fruit. A brief description or definition of the different types of fruit is desirable before studying any classification of them. Standard botanical works should also be consulted for a fuller treatment. Several types have no special interest for the pomologist.

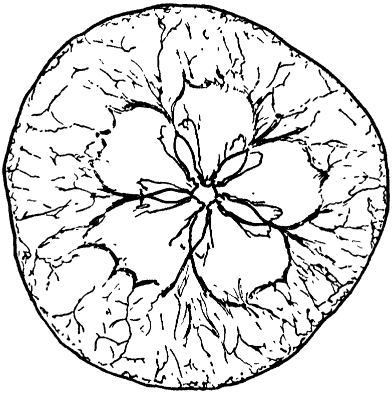


FIG. 24. Cross-section of Delicious apple cleared in xylol to show vascular system and fleshy exocarp.

A. Dry fruits (pericarp dry).
  1. Dehiscent, those in which the seeds are dispersed or fall from the fruit when it is ripe.
    (a) Legume. A one-carpel fruit in which splitting occurs along both sutures. Pea, bean, vetch. Exceptions are found as in the peanut which must be cracked open along the sutures, and in St. John's bread *Ceratonia siliqua.*
    (b) Follicle. Consists of one carpel which splits along the adaxial (ventral) side only. Milkweed. Frequently several are associated together as in Columbine (apocarpy).
    (c) Capsule. Two or more carpels are associated together (syncarpy). Poppy, okra.
    (d) Silique. A several-seeded fruit consisting of two carpels with a septum or partition between. The fruit is flattened and the two valves (carpel walls) open from below upwards. The marginal placentae remain and the seeds are left (temporarily) lying against the membranous partition. Cabbage, lunaria.
  2. Indehiscent, not splitting open when ripe.
    (a) Achene. A one-seeded fruit in which the seed is attached to ovary wall at one point. A nutlet as in strawberry.
    (b) Caryopsis (grain). A one-seeded fruit in which the seed coat and pericarp are united throughout. Corn, wheat.
    (c) Samara or "Key" fruit. A one-, two-, or rarely three-seeded fruit in which the pericarp is expanded into a wing-like structure. Elm, maple.
    (d) Schizocarp or Cremocarp. In which two achene-like fruits are united until mature when they separate but frequently remain attached to a slender axis or carpophore. Each one is termed a mericarp. Parsnip.
    (e) Nut. A fruit in which the carpel wall is hard or bony in texture. It may be derived from an hypogynous flower (filbert) or an epigynous one (black walnut), and it may be inclosed in a fleshy or a dry receptacle. It is usually one-seeded but in most cases is derived from

two carpels. The almond is a drupe until mature when the exocarp is shed and the endocarp only encloses the seed. In the case of the Brazil nut, *Bertholletia excelsa,* as seen on the market, the seed only is involved, the stony covering being the outer seed coat. Thus the term "nut" may refer to a number of different structural situations.

B. Fleshy Fruits. In contrast to the fruits which become dry or nearly so at maturity there are many which are fleshy or somewhat succulent at maturity and others in which a part of the structure remains fleshy and another part or parts becomes dry or essentially so. There are, of course, shadings of one type into another so that close or definite classification is rather arbitrary. The above distinction holds where only the carpel wall is involved in the fruit and also where both carpel wall and some other structure or structures enter into the fruit. These distinctions are recognized in the classification which follows.

Berry. A berry is a fruit in which the parts remain succulent or nearly so. It is recognized that the seed is not a part of the fruit structure but rather borne within or on the fruit. This definition applies to both true and false fruits. If one wishes to make clear the morphological situation, he could speak of "superior berries" and "inferior berries" but this is scarcely necessary although the situation should be clearly understood. A berry may or may not have seeds and may have one or several carpels. The exocarp may separate readily from the mesocarp when ripe as in the American type of grape or be undiverged as in *Vitis vinifera.* The receptacle may also separate as in the banana (the skin) or it may be undiverged from the carpel wall as in the cucumber or cranberry.

It will be noted that the strawberry is not a berry since the carpels are achenes with a fleshy receptacle, and that the raspberry and blackberry being composed of groups of drupelets are therefore not berries.

In the case of citrus fruits such as the orange, lemon, grapefruit, lime, and tangerine the exocarp becomes somewhat leathery while the endocarp is membranous. This type of a berry is called an hesperidium.

In the *Cucurbitaceae* the outer wall, which is receptacle, becomes hard, or nearly so, upon maturity and such a berry-like fruit is called a pepo. The squash, pumpkin, and cucumber are examples. In the turban type of squashes the carpels are exposed at the apical end which gives rise to the term "acorn" in descriptive literature. The flower in such cases is semi-epigynous.

In the pineapple the outer surface of the fruitlets including the tips of the bracts are tough and are discarded.

In the Capsicum, a type of pepper, the tissues dry as the fruit ripens, thus being a "dry" berry.

Drupe. This type of fruit is usually derived from a single carpel. The olive is an exception in that the flower has two carpels and four ovules but only one carpel develops. Two ovules are borne in most drupes but usually only one seed develops. In the conventional type of drupe the pericarp in developing becomes divided into three distinct layers, (a) the exocarp or "skin," (b) the mesocarp which often becomes fleshy or pulpy as in the peach or thinner and hull-like as in the almond, and (c) the endocarp or "stone." (Fig. 25.) The peach, plum, cherry, and apricot are typical drupes. In the almond the exocarp and mesocarp become dry and are removed before shipping to market so that only the endocarp containing the edible seed appears on the market. In the cocoanut the mesocarp is fibrous and the endocarp consists of the hard shell which encloses the meaty endosperm of the seed.

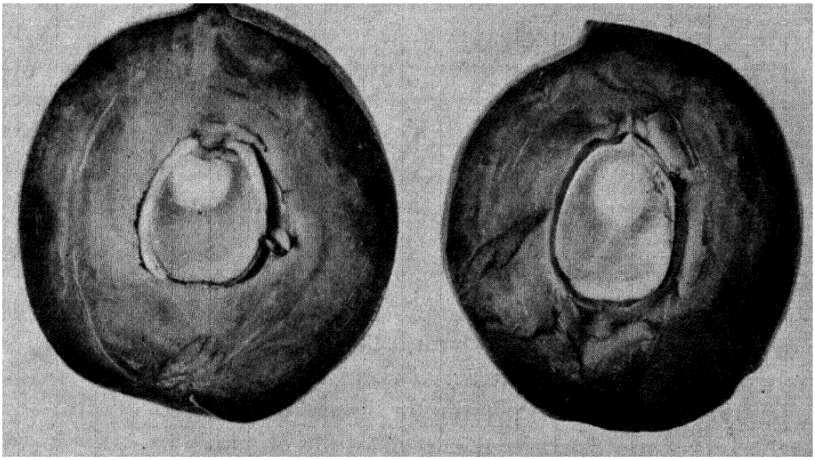


FIG. 25. Medium longitudinal section of young peach fruit. Inner area represents stony endocarp, the outer surface is the exocarp or skin, and area between the exocarp and endocarp is the mesocarp or flesh of peach. Also note young developing embryo at the tip of seed with partly developed endosperm adjacent and remnants of nucellus at the basal region.

The black walnut is often classed as a drupe but differs from the others mentioned in that it is derived from an epigynous flower and the fleshy outer wall is receptacle and the stony portion is the pericarp.

The seed of the ginkgo tree has sometimes been classed as a drupe because it resembles such fruits, but this is untenable since the structure is not a fruit but a seed. The outer seed coat has become fleshy as is true in the Yew.

Pome. The pome type of fruit is one in which the several carpels are leathery, or partially so, and ranging to nearly stony, in some forms. The receptacle becomes fleshy and constitutes the edible portion. The apple, pear, quince, and loquat are familiar examples. (Fig. 24.)

The Seed

A seed may be defined as an embryo sporophyte with or without a reserve food supply (endosperm) and with or without seed coats. Associated with the embryo at maturity may be an endosperm (albuminous seeds) or perisperm (remnant of the nucellus). Not all seeds are fully developed at the time they are shed (as orchids), and some are so fully mature as to germinate within the fruit (viviparous).

Classification of fruits. Fruits may be classified on more than one basis, *viz.*, dry or fleshy consistence of fruit; dehiscent and indehiscent; simple, aggregate, and multiple; "true" and "spurious" or "false" fruits; and the number of carpels and other parts involved, depending upon the viewpoint or interest. The horticulturist is furthermore interested in a classification of varieties quite apart from any botanical consideration, which is termed "systematic pomology." In standard botanical works will be found various classifications to which the student should refer. For our purpose here it is desired to emphasize the nature of the fruit wall (whether dry or succulent), the number of carpels involved, and the presence of conspicuous parts other than the carpel wall. The list here given may be expanded on those bases.

It will be noted that the matter of dehiscence is not important with most fruits in which the pomologist is particularly interested. They are either fleshy or part dry and part fleshy. Even the peanut, which is a legume, does not dehisce at maturity. Most of the other nut fruits, as hickory, pecan, and filbert, are also indehiscent although they may shed the husks (bracts). The student may add many other examples to the classification here appended. The following classification is suggestive of the structure and consistence of fruits.

A CLASSIFICATION OF FRUITS

(Including Fruitlets)

Consistency	*Structure*			
	One Carpel	*Two or More Carpels*	*Two or More Carpels + Stem Axis*	*Carpels + Stem Axis + Accessory Parts*
Dry Indehiscent	*Caryopsis* Corn Wheat Oats Rye *Achene* Strawberry fruitlet Rose fruitlet Fig fruitlet Osage Orange fruitlet Hop fruitlet *Legume* Peanut Carob (St. John's Bread)	*Utricle* (Modified achene) Buckwheat *Schizocarp* (Modified achene) Carrot Celery *Key* (Modified achene) Maple Elm Ash Tree of Heaven *Silique* (Modified capsule) Radish	*Capsule* Brazil Nut *Multiple Fruit* Corn (Ear)	*Multiple Fruit* Hop (Strobilus)
Dry Dehiscent	*Follicle* Milkweed Columbine Larkspur Peony Magnolia fruitlet *Legume* Pea Bean Lupine	*Capsule* Okra Cotton Tobacco *Silique* (Modified capsule) Mustard *Silicle* (Modfied capsule) Shepherd's Purse	*Capsule* Sapucaya Nut Iris *Aggregate Fruit* Magnolia	
Dry-Fleshy	*Drupe* Peach Plum Cherry Almond Olive Mango Raspberry fruitlet	*Drupe* Coconut	*Pome* Apple Pear Quince Loquat Pomegranate *Aggregate Fruits* Raspberry	*Nut* Filbert Acorn Chestnut Hickory Walnut Pecan Cashew

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A CLASSIFICATION OF FRUITS—*Continued*

(Including Fruitlets)

Consistency	*Structure*			
	One Carpel	*Two or More Carpels*	*Two or More Carpels + Stem Axis*	*Carpels + Stem Axis + Accessory Parts*
Dry-Fleshy	*Drupe* Blackberry fruitlet Mulberry fruitlet		*Aggregate Fruits* Blackberry Rose (Hip) Strawberry	*Multiple Fruit* Fig (Syconium) Mulberry
Fleshy	*Berry* Avocado Mayapple Date Pineapple fruitlet Ceriman fruitlet Sugar apple fruitlet	*Berry* Grape Persimmon Tomato Sapodilla Papaya *Hesperidium* (Modified berry) Orange Lemon Grapefruit Lime Kumquat	*Berry* Blueberry Cranberry Currant Gooseberry Banana Tuna (Prickly-pear) *Pepo* (Modified berry) Watermelon Cucumber Pumpkin Squash	*Multiple Fruit* Pineapple Ceriman Osage Orange Breadfruit

Structure of Specific Fruits

It is not our purpose to describe in detail the various fruits but rather to cite examples of the more familiar ones, based on the foregoing classification. The student should have fresh fruit of each kind at hand and examine it, as far as possible, with the flowers of the same before him. Preserved specimens of flowers serve the purpose quite well.

Peach, plum, and cherry. These fruits, together with the apricot and almond, may be considered together as their basic structure is similar.

The flower structure of the peach (*Prunus Persica*) Fig. 21, has the characteristic receptacle cup of this group, and the origin of the sepals, petals, and stamens on its rim. This shuck, together with its dried floral remains, is shed a few days after full bloom leaving the pistil to develop as the fruit. Only one of the two ovules usually develops into a seed, and rarely, when the ovules are frozen there are occasions when perfectly normal fruits develop without any seed (1938).

Upon development of the fruit three distinct regions differentiate, the inner or stony layer of the carpel wall which becomes the pit and is termed the endocarp. The fleshy or edible portion which is the mesocarp, and the outer layer or "skin" which represents the exocarp or epicarp. All three taken together compose the pericarp. (Fig. 25.)

In the almond the meso- and exocarp dry upon maturity and are removed before marketing. The shell of the almond of commerce is, therefore, the endocarp or "stone" and the edible portion is the seed.

Raspberry. The raspberry is an aggregate fruit in that there is only one pistil or gynaecium but it consists of a number of carpels each of which is a small drupe, or drupelet. The cluster of drupelets separates readily from the receptacle at maturity and adheres in a thimble-shaped group although there is no organic union between them.

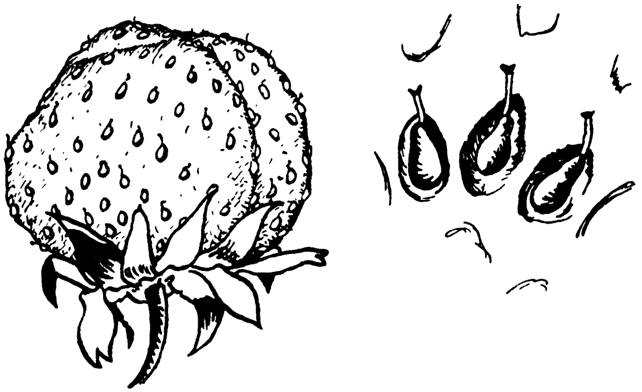

FIG. 26. Fruit of strawberry with individual achenes to the right.

The leading varieties are red, black, and purple, although yellow ones also occur.

Blackberry. The blackberry resembles the raspberry except that the drupelets remain attached to the receptacle which is picked with them. The styles are about half the length of those of raspberries.

Strawberry. The flower of *Fragaria* is characterized by 5 (or more) large green bracts which alternate with the 5 (or more) sepals producing what is termed an epicalyx. There are 5 or more white petals, numerous stamens in some varieties and none or only abortive ones in others, and many carpels distributed over the receptacle. The styles of the carpels arise near their bases on the ventral or adaxial side. Upon ripening the receptacle becomes large, fleshy, and gives to the fruit its succulence. The individual carpels ripen into achenes bearing a single seed. (Fig. 26.)

Citrus. While morphological variations occur among citrus fruits the general plan of structure is the same. These fruits are berrylike but because of the leathery rind (epi- and mesocarp) the special designation of *hesperidium* is given to them. The individual carpels are surrounded by the inner mesocarp (albedo) and endocarp which is membranous. Many lysigenous oil glands are found in the outer rind and in the style and stigma of the hypogynous flower. (Fig. 27.)

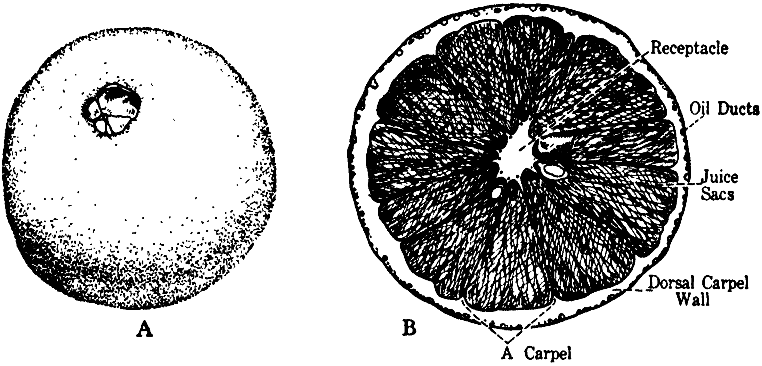

FIG. 27. A, navel orange in which the "navel" results from a second set of small carpels arising at terminus of receptacle; B, cross-section of a Valencia orange.

The edible portion of citrus is composed of juice sacs or vesicles which arise from the inner walls of the endocarp.

The central column of pithlike material constitutes the receptacle and in the navel orange a set of supernumerary carpels arise at the distal end of this receptacle.

Grape. The fruit of the grape is a true berry, in most cases consisting of 2 carpels. The epicarp of American varieties (*Vitis labrusca*, *V. aestivalis*, et al.) is easily freed from the mesocarp or pulp upon ripening, while it is not diverged in the European sorts (*V. vinifera*). A septum separates the 2 carpels although this is not conspicuous. The number of seeds varies from the full complement of 4 to none.

Gooseberry. The gooseberry, like the currant and blueberry, is an example of a berry derived from an epigynous flower so that the wall of the fruit is derived from both carpel and receptacle. The ovules appear to be borne on the walls of the ovary and are said to be *parietal.* They are actually borne on the edges of the two carpel walls, however, hence the term parietal in this case is misleading.

Apple. The apple may be taken as an example of the pome fruits. As indicated earlier, the characteristic of this group is the several carpels (5 in the apple, pear, and quince) surrounded by a fleshy receptacle. The flower is usually interpreted as epigynous, but some botanists prefer to consider it perigynous after the fashion of the rose hip, except that the hypanthium is adnate to the walls of the carpels. As shown in Fig. 28 the sepals and stamens arise above the carpels, and since these organs diverge from receptacle tissue, the usual interpretation is that the fleshy portion is receptacle or hypanthium. Figure 24 shows an apple in cross section as drawn from an actual section of a Delicious apple cleared in xylol. The leathery carpel walls have a fleshy epicarp which does not appear in uncleared sections. The white area outside the carpels, within the "core lines" is the pith of the receptacle; the five bundles opposite the carpels together with the five between them constitute the toral vascular strands which supply the sepals, petals, and stamens.[10] Outside these ten bundles lies the cortex or main fleshy

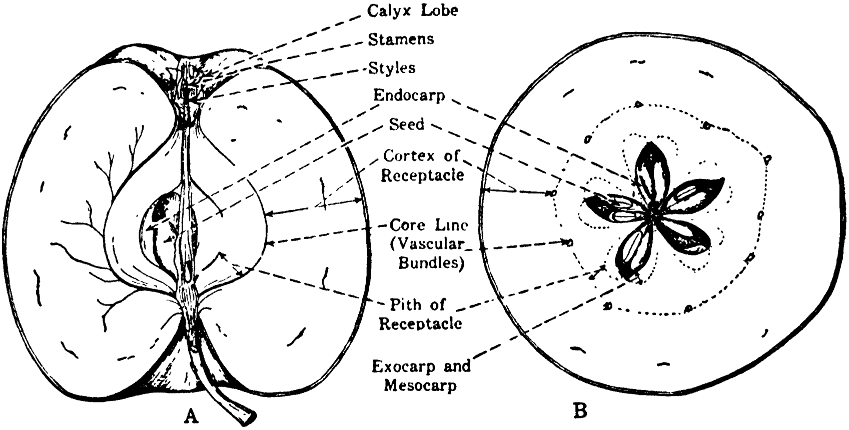

FIG. 28. A, median lengthwise section of mature apple; B, cross-section of same. (From Robbins, *Botany of Crop Plants*, P. Blakiston's Son and Co.)

portion, and the skin is the epidermis and hypodermis together with closely packed cells of the outer cortex.

Banana. This fruit is classed as a berry and develops from an epigynous flower. The skin (receptacle) separates from the three carpels when ripe. The fruit of commerce is seedless but bears a full complement of ovules. The three locules are practically closed and the walls of the carpels are fleshy and occupy the entire space. (Fig. 22.)

Pineapple. In the pineapple (*Ananas sativus*) the whole axis or stem of the plant is beset with closely crowded fruitlets derived from epigynous flowers. By dissecting an individual fruit the three carpels, characteristic of monocots, can be clearly seen, although no seeds develop. (Fig. 29.)

The axis is fleshy as well as the carpel walls, receptacle, and base of the bracts, and is classed as a berry. This presents an unusual situation among fruit plants.

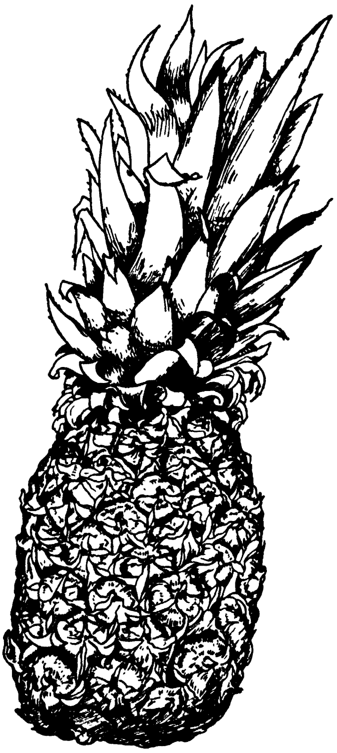

FIG. 29. Multiple fruit of pineapple.

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3

FACTORS AFFECTING FLOWER FORMATION

Since the environmental factors associated with flower formation were not seriously considered until the latter half of the 19th century, a study of the physiological basis of this phenomenon was necessarily retarded. During the last two decades, however, the chemical aspects of the problem have received an ever-increasing amount of attention, due primarily to the stimulating effect of the work of Kraus and Kraybill. Furthermore, within recent years the problem of photoperiodism and its practical applications, together with increasing interest in the role of phytohormones, have accelerated research for determining the causal agent or agents of flower-bud differentiation.

Physiological Basis

Sachs, the German botanist, who was one of the first to concern himself with this problem, concluded that flower formation was the result of a "flower-forming substance" (Blütenbildender Stoff) developed by the leaves which diffused to the buds in the leaf axils and there induced flower formation.[36]

He came to this conclusion on the ground of experiments with several plants including *Phaseolus*, *Tropaeolum*, and the gourd. He found that flowers differentiated on those portions of the stem which were kept in total darkness, provided the basal portion of the plant contained leaves which were permitted to function in the light. In one instance he removed the leaves from the upper portion of the stem growing in darkness; in the other he directed the growing apical portion of a gourd plant containing 10 to 12 good leaves into a darkened chamber where growth nevertheless continued and flowers differentiated. He concluded (Marshall Ward translation, page 533) "the growth of the organs enclosed in the dark cavity is so much the more vigorous and normal the larger the assimilating leaf area exposed to the light is, and the more intense the light itself is outside the box. . . . Of especial interest in all these cases is the unusually vigorous and normal production of flowers and fruit, so long as the assimilation of the leaves exposed to the light proceeds energetically." [37] It is obvious that from this type of experiment it cannot be established that the "flower-forming substance" is of the nature of carbohydrates or a hormone or both. Early in the 20th century it was presumed that this flower-forming substance or substances was in the nature of carbohydrates. This conclusion was due largely to another physiologist, Klebs, who outlined more specifically the environmental conditions conducive to flower formation.[30] The supply of available nutrients, particularly nitrogen, and light intensity as it affects the production of carbohydrates, were believed to be the controlling factors in determining whether the plant would remain vegetative or form flowers. His conclusions were based on almost continuous observation of plants for over 20 years. Meanwhile Fischer,[13] after studying the effects of carbon dioxide upon growth and flowering, concluded that when the supply of carbohydrates was relatively high in proportion to available nitrogen flowers were differentiated. When the nitrogen was high in relation to carbohydrates, the plants failed to flower. At this time (1905) he suggested that the factor involved was a balance of carbohydrates over nitrogen, while in 1916 [14] he went so far as to place the question of flower formation on the basis of a definite *ratio* between carbohydrates and nitrogen, an idea which has erroneously persisted in the literature even up to the present time.

The work of these investigators, however, involved no chemical evidence to lend support to their conclusions. It was at this point that Kraus and Kraybill [31] presented the now classical work in which for the first time chemical data demonstrated the relationship between the composition of a plant and its fruiting response. While the data presented were concerned almost entirely with the conditions associated with the development of *flowers* into *fruits* in the tomato, nevertheless, their work has been of great importance in stimulating research to determine the physiological basis of flower formation. Despite the fact that their results have at times been rather widely quoted in substantiation of conclusions obtained in flower differentiation studies, yet the authors themselves appreciated the fact that, though the two problems are related in some respects, flower-bud formation and fruit setting are still separate phenomena. That this is true is indicated by the following statement found in the introduction to their paper: "The material reported and the viewpoints expressed in this paper embody some of the results of such a study undertaken in connection with the fruit-setting problem insofar as it is concerned with higher plants." In the summary, furthermore, they warned against misinterpretation in the following statement: "The conditions for the initiation of floral primordia, and even blooming, are probably different from those accompanying fruit setting."

Inasmuch, however, as carbohydrates and nitrogen are undoubtedly essential to flower formation as well as to fruit setting, the relationship of these substances is pertinent in both cases although the specific results cannot be interchangeably applied.

Following chemical analyses of the stems and leaves of tomato plants, Kraus and Kraybill classified plants in four groups, Classes I, II, III, and IV. These groups are based on differences in the relative nitrogen and carbohydrate content of the plants and their various organs such as stems and leaves. The characteristics of plants in these groups may be outlined as follows:

Class I. The plants included in this group are those which are decidedly carbohydrate-deficient. This deficiency, it is to be emphasized, is induced by a low rate of carbohydrate manufacture, due to shading, defoliation, or other factors which greatly reduce the rate of photosynthesis. The plants have light green foliage and soft, willowy, spindly stems. The length growth may be considerable, but the diameter increase small. Such plants are termed weakly vegetative. In the tomato the flower fails to reach anthesis (full bloom) and therefore cannot set fruit.

Class II. The plants included in this group are rank-growing and vigorously vegetative with large, thick stems and leaves. The color of the foliage is dark green. In the tomato the flowers reach full bloom but fail to set fruit, a fact which will be considered in Chapter 10 on fruit setting. It is now evident that the plants in this class are affected by a mild carbohydrate deficiency. This deficiency results not from failure of carbohydrate synthesis but rather as a result of rapid utilization of carbohydrates in the formation of organic nitrogenous compounds (in the presence of an abundant supply of inorganic nitrogen). The difference in growth between the plants of Class I and II is indicative of a difference in the degree of deficiency of reserve carbohydrates.

Class III. The plants included in this class are those which flower and fruit abundantly as a result of sufficient carbohydrate and nitrogenous substances. Carbohydrates are not limiting as in Classes I and II.

Class IV. The plants in Class IV make little vegetative growth and are also known as weakly vegetative, as are the plants in Class I. The foliage tends to be of a yellowish cast, and the growth of all vegetative parts is restricted. As opposed to Class I, nitrogen is the limiting factor. Furthermore, as a result of restriction in the synthesis of organic nitrogenous compounds from inorganic nitrogen and carbohydrates, the reserve carbohydrate content is high, being more or less proportional to the degree of the deficiency of nitrogen.

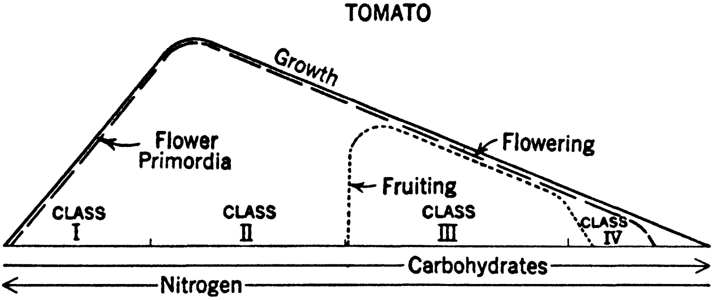

FIG. 30. Relationship of the nitrogen and carbohydrate composition in the tomato to its growth, flowering and fruiting.

These classes are primarily of value in presenting in a rather specific manner the relationship between the composition of the plant, as regards nitrogen and carbohydrates, and its response in flowering and fruiting. This relationship has frequently been presented in a graphic manner and has enabled one to predict the efficiency of a given treatment in changing or altering plant response. In order to clarify the differences between the tomato and the apple in respect to flowering and fruiting in each of the four classes, two charts, admittedly arbitrary, are presented: Fig. 30 for the tomato and Fig. 31 for the apple. Growth as indicated in this chart is predicated on the basis of fresh or green weight and is considered to reach its maximum in the vigorously vegetative plants characteristic of Class II. In the tomato it is to be noted that flower primordia are formed both in the plants of Class II and in the weakly vegetative plants of Class I, while, on the other hand, no flowers are differentiated in the vigorously growing apple trees of Class II. In both the tomato and the apple, the plants of Class II are unfruitful, in the former instance because of the *failure of the flowers to set fruit*, in the latter because of the *failure of flowers to be differentiated*. It is also to be noted that some flower formation occurs in the plants of Class IV which are deficient in nitrogen but that fruit setting is more limited. This is evident under field conditions where plants, deficient in nitrogen, are frequently observed to form many flowers, but later show few fruits developing therefrom. Obviously the plants which make little growth because of nitrogen deficiency are limited also in flower formation since floral primordia are usually differentiated in the common fruit plants on the current season's growth.

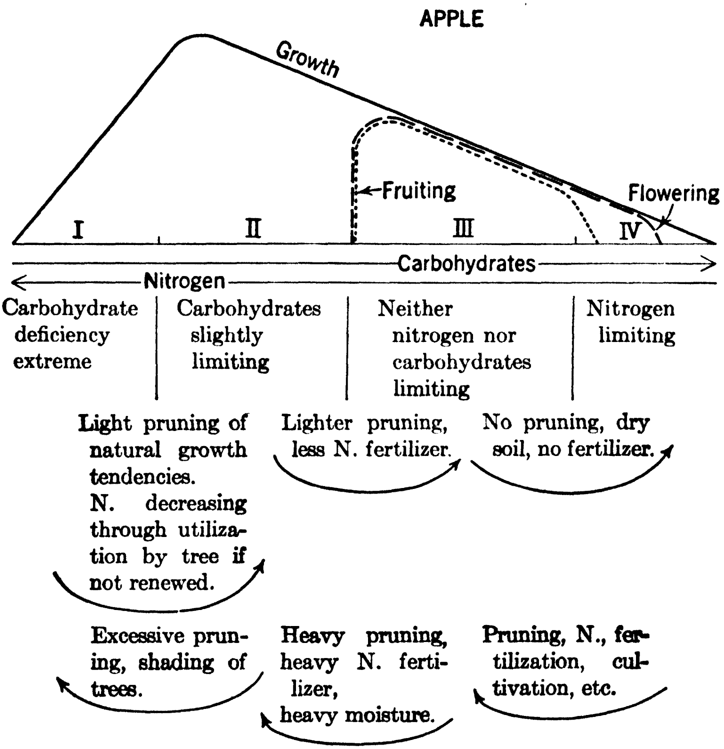
APPLE
Growth
Fruiting
Flowering
I
II
III
IV
Carbohydrates
Nitrogen
Carbohydrate deficiency extreme
Carbohydrates slightly limiting
Neither nitrogen nor carbohydrates limiting
Nitrogen limiting
Light pruning of natural growth tendencies. N. decreasing through utilization by tree if not renewed.
Lighter pruning, less N. fertilizer.
No pruning, dry soil, no fertilizer.
Excessive pruning, shading of trees.
Heavy pruning, heavy N. fertilizer, heavy moisture.
Pruning, N., fertilization, cultivation, etc.

FIG. 31. Relationship between the nitrogen and carbohydrate composition in the apple and its response to various cultural treatments with respect to flowering and fruiting.

Figure 31 shows the relationship between composition, treatment, and tree response or behavior. The effect of treatments in changing the plant from one class to another or from one chemical composition to another is indicated here. The outline is suggestive of means of regulating the growth behavior of the trees. It illustrates an important application of the work of Kraus and Kraybill, namely that some orchard practices have often a double and apparently opposite effect. For example, pruning trees deficient in nitrogen induces more fruitfulness; while pruning of young, vigorous nonflowering trees delays fruitfulness. In other words, it is not the practice itself which governs the particular results obtained, but the composition of the plant and its consequent response as related to the various food materials.

Chemical data presented by other investigators. Following Kraus and Kraybill, other investigators presented chemical evidence concerning the physiological basis of flower formation. The work of Hooker [27] at Missouri was outstanding in this respect, and formed, according to Tottingham,[40] "a climax to this line of investigation." The seasonal changes in the chemical composition of apple spurs were observed throughout a 2-year cycle. Carbohydrate-nitrogen relations were determined at the normal time of flower-bud differentiation. These chemical analyses were made of the nonfruiting spurs, which would thus be expected to differentiate flowers, and of the fruiting spurs which under these circumstances

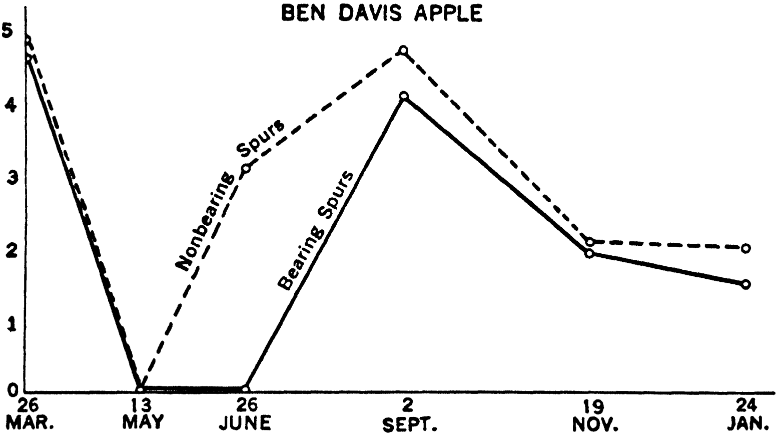

FIG. 32. Graphic presentation of the starch content of bearing and nonbearing spurs during the period from March 26 to January 24. (After Hooker.)

usually fail to flower. At the time of differentiation the nonbearing spurs showed less total nitrogen and reducing sugars but more starch and hydrolyzable polysaccharides. Starch, in particular, accumulated at the time of floral differentiation only in those spurs presumably forming flowers. This conclusion is supported by the data presented graphically in Fig. 32. As a result of this and further work, Hooker concluded that a "low percentage of blossom-bud formation is a direct result of a carbohydrate deficiency."

The chemical analyses of other investigators also showed that a larger amount of carbohydrates, particularly starch or sugar, were present in spurs which were to initiate floral primordia than in comparable parts in which flower formation was not taking place.[9, 20, 33] Recently, additional data of a similar nature have been obtained in the peach [43] and in the Sultana grape in which a close correlation was observed between the amount of starch in the *annual wood* and flower-bud formation.[41]

Flower-producing hormones (florigens). That substances of the nature of phytohormones may be concerned in the initiation of floral primordia is indicated by recent research.[5, 19] It must be admitted that Sach's "flower-forming substance" might be considered a hormone since these substances, like carbohydrates, are formed by the leaves, and light is necessary for their elaboration. Furthermore, ever-increasing evidence indicates that the hormones and sugar are interdependent in their action on the growth processes of plants. The evidence presented in the foregoing sections, as well as the results of studies on the effect of environmental factors on flower formation, emphasize the paramount importance of leaf surface in flower-bud differentiation in the fruit plants. Future research may indicate the exact nature of these substances which, together with a carbohydrate food supply, are responsible for the initiation of flower-buds. The present position in regard to the physiological causes of flower differentiation is summed up from a horticultural viewpoint by Gourley as follows: [15]

"Other more specific substances than carbohydrates and organic compounds are receiving attention as the primary causal agent of flower initiation, and interesting evidence is at hand; but in any event it is in the green leaves or other green organs that these substances find their origin. The horticulturist need not at this time quibble over, nor greatly concern himself as to whether some hormone or flower-promoting substance is more important than the food constituents in accomplishing the desired results. The fact still remains that flowers and their end products, —fruits and seed, are composed largely of the products of photosynthesis and of organic nitrogen complexes. It is the green leaf, unharmed by insect, disease, caustic spray solution, or other extremes of environment that tells the story."

Environmental Factors Affecting Flower-Bud Differentiation

A considerable body of knowledge has accumulated regarding the effect of various environmental factors and treatments upon the formation of flowers. Several practices which stimulate flower formation have been known and used by amateurs for centuries. Not all are pertinent in the light of present knowledge; their chief value lies rather in the indirect evidence which they present concerning the conditions associated with flower formation. Root pruning, for instance, by reducing the absorption of nutrients and water, increases flower formation.

Light. Intensity, duration, and quality of light are known to affect the differentiation of floral primordia in horticultural plants. Since there is little information concerning the effect of quality of light upon flower formation in fruit plants, only intensity and duration will be considered here.

Intensity of light. Light of high intensity favors flower formation in fruit plants. It is commonly observed that in the interior of even well-cared-for trees, the light is considerably lower than at the periphery, while within dense, unpruned trees the intensity may be so low as to greatly reduce flower formation. Meter tests show that light of only 500 foot candles is quite common in the interior of an apple tree, as compared with 5,000 to 10,000 foot candles at the periphery. Thus at the innermost portions of the tree, slender shoots and spurs give evidence of a poorly functioning leaf surface, and, as a result, these entities may fail continuously to flower. Experiments show that bearing peach and apple trees, shaded by muslin during the spring and summer formed very few flowers. In New Hampshire shading the peach also reduced its branching and decreased the number of leaves developing at the nodes.[17] This modification not only reduced the number of leaf buds but also prevented the initiation of floral parts in those buds which did develop. The leaves of the shaded trees were larger in area but thinner, and the growth of spurs and shoots more attenuated and willowy. With severe shading the spurs and branches finally died. In Maryland,[2] shading Stayman Winesap trees also greatly depressed flower formation despite the fact that no fruits were borne on the trees during shading. It is interesting to note that shading in the spring, up to within five weeks of the time when flower differentiation normally begins, also reduced flower formation. Chemical analyses of the shaded and unshaded portions of the trees showed that this condition was associated with a lower nitrogen content (both soluble and insoluble) and higher total sugars and starch.[2, 32]

Strawberry plants *darkened* in midwinter formed few flowers, and the stamens were entirely lacking. The pistils, although better developed than the male organs, were very small.[8] Light of low intensity also tends to prevent development of functional anthers.

Duration of light. Shading is not to be confused with a shortened length of day which in some ("short-day") plants increases flower differentiation. Most of the tree fruits have not been found to respond specifically to definite light duration as have many other plant species. On the other hand in the strawberry, flower formation is definitely influenced by the duration or length of the daily light period (and thus of the night period) although temperature has a modifying influence upon this reaction.[7, 8, 42]

Varieties of strawberry differ in their response to this factor. On the one hand the short-day, commercial varieties differentiate flowers most satisfactorily during days of thirteen hours or less, while the so-called ever-bearing types form flowers during the long, summer days even at relatively high temperatures. In addition, the short-day varieties must again be subdivided into varieties suitable for use in the North or in the South, since flower and runner formation, which are more or less antagonistic, must undergo a somewhat complicated adjustment to length of day in relation to temperature.

Maximum fruit development depends upon a compromise between flower formation and runner development. A decreased light period induces flower formation at the expense of runners, while the longer day length tends to induce runner rather than flower formation.

Although short days favor flower formation, regardless of temperature, yet temperature, to a certain extent, modifies the day-length response. In general, any decrease in temperature increases the length of day which will permit flower formation. In California, for instance, during the cool summers along the Pacific coast, flower clusters are formed even during the summer in mature strawberry plants. The yields there reported are, according to Darrow [7] the highest per acre in the world for this summer crop. Further north in Oregon and Washington where the summer days are longer fruit production is considerably less.

The difference in the day-length temperature reaction is responsible for the fact that some varieties are better adapted to the North, others to the South. Varieties such as Klondike and Missionary show a more satisfactory balance between runner and flower formation under Southern conditions than do the Northern varieties such as Premier (Howard 17) or Dr. Burrill. In general, the most important point is the fact that although certain short-day varieties will form flowers either in the North or in the South, the relative proportion of runners and flowers formed differs in the two regions. A variety adapted to the South should form a satisfactory number of runners previous to and accompanying flower formation in order to induce a large yield of fruit per plant. Northern varieties planted in the South show low yields, because flower formation is not preceded by sufficient runner development. In general, the extremes of day length and high temperature produce extreme runner formation, while short-day, low-temperature conditions induce intensive flower formation. Modifications of all these factors produced modified results.

Ringing. Ringing or girdling involves the removal of a ring of bark from the trunk or branches of a tree. When two or more cuts are made around the stem to the depth of the cambium, but no bark is removed, the operation is called "scoring." Ringing or girdling has been practiced for many years, particularly in Europe, as a means of inducing flower formation. Other less familiar methods have also been used, such as "notching" below a bud, removing strips lengthwise from the bark ("stripping"), or driving nails into the trunk. A label wire left at planting time may frequently girdle the trunk or branch thus resulting in flower formation. Results similar to those obtained by ringing are often observed in the field when a tree is injured by low temperature, fire, disease, cankers, or is girdled by rodents.

Considerable study has been given to the effect of ringing upon the chemical composition of the portion of the plant above the ring. All available data indicate that girdling results primarily in the accumulation of carbohydrates above the ring,[32] while the change in nitrogen seems to be of much less significance.

Ringing in commercial practice. Ringing is of minor importance to the commercial grower since it is seldom necessary, with mature trees, to stimulate flower-bud formation artificially. Young trees of most varieties also bear soon enough, and so the practice is of consequence chiefly in the case of filler trees which are tardy in forming flowers, and in hastening the bearing of seedling apple and pear trees where breeding work is in progress. However, the fact that the beneficial effects of the operation need not be followed by unfavorable aftereffects has to some extent renewed the interest in the practice.[12, 16]

Specific directions for ringing. In the first place, the practice should never be used with stone fruits, for in this case it invariably results in injury.[39] In addition, trees which have, for any reason, become devitalized are also less likely to respond to the practice. Furthermore they do not recover readily, and injury or death may result. Very young trees and small limbs are not responsive.[16] Neither will ringing induce flower formation, if the leaf surface above the ring has already been depleted.[18] Finally, ringing alternate bearing trees cannot be expected to induce flower formation for the "off" year.

The operation must be performed 3 to 5 weeks previous to the time when flower differentiation normally occurs, namely during late May or early June, in northern United States. While the entire trunk of the tree may be ringed it seems preferable to treat only one or two major limbs at a time, followed by an equal number the subsequent year.

Scoring (which consists of 2 or 3 parallel cuts) produces a less objectionable wound and the results are nearly as satisfactory. It is now known that the width of the ring need not exceed a quarter of an inch since wider rings have resulted in considerable injury.[12, 16, 28] In addition the wound should be covered to prevent the entrance of bacteria and other microorganisms.[11] Waxed muslin strips, bicycle tape, or some other suitable substitute containing no ingredient injurious to plant tissue may be used. In covering the wound with tape, care should be exercised that the protective material is kept from touching the surface of the exposed wood or healing may be prevented. Shoots starting to develop near the ring must be removed, and if blight organisms (*Bacillus amylovorus*) are likely to enter at this point, an asphalt wound dressing should be used for protection. Care must also be taken that ringing does not spread blight.

Root pruning. Severe injury to the roots of fruit trees has frequently, though not invariably, increased flower formation.[11] In Europe root pruning has long been employed by amateurs to induce flowering in young vigorous trees which are tardy in forming flowers. In order to produce this desired effect the operation, which is usually quite severe, must take place a few weeks prior to the time when flower differentiation should occur.

In principle, this practice reduces the entrance of water and nutrients, thus retarding the growth of shoots and spurs. This retardation in growth, as previously indicated, is associated with differentiation. The practice has never been commercially adopted in America since a maximum root area is advocated because of its favorable effect upon other functions of fruit plants.

Bending. This operation consists of bending the larger branches downward so that their main axes are in a more or less horizontal position. In the older horticultural literature the operation is frequently mentioned, particularly in connection with increasing flower formation on young pear trees. This method is not of much commercial importance since it is less dependable than either ringing or scoring. It has been used commercially, however, in a few Bartlett pear orchards in California and Washington, although only experimentally in the East. The theory involved is that the rate of growth of the branches is retarded by their horizontal position and thus the accumulation of materials inducing flower formation, occurs.

Dwarfing rootstocks (*understocks*). The dwarfing of fruit trees, a process accomplished by grafting or budding varieties on slow-growing rootstocks hastens flower formation. (See Chapter 15.)

The effect of these stocks is a retardation of the rate of growth of shoots and spurs, a factor associated with flower production.

Defloration. Complete defloration usually results in abundant differentiation of floral primordia for the succeeding year's crop, thus indicating that certain materials utilized in fruit development are also required for flower formation. Furthermore, a complete defloration of individual branches on a tree will usually induce the differentiation of flowers for the succeeding year, while the fruiting portion shows no effect.

The effect of partial defloration upon annual flower formation varies with different varieties. In Baldwin, even a small proportion of developing fruits seems to prevent flower formation. However, in Yellow Newtown and Ortley, an approximate set of 3 per cent (6 to 10 per cent is more or less equivalent to a full crop) still permitted flower formation.

Defoliation. The removal of a leaf subtending a bud invariably prevents the differentiation of flowers in that bud, even though other leaves are present at adjacent nodes.[35] Since this is true, complete defoliation, occurring as a result of disease or injury of any sort, may either prevent or greatly reduce flower formation. The removal of even a portion of the leaves will frequently produce a similar, though less severe, effect. Defoliation, to be thus detrimental must naturally occur slightly before or during the differentiation period.

Chemical analyses of shoots and spurs from which the leaves were removed shows a marked reduction in total sugars, starch, and total carbohydrates as a result of defoliation.[21, 43]

Effect of acetylene and ethylene. Recently acetylene and ethylene have been found to have a favorable influence upon flower differentiation in the pineapple. These substances have been used in a limited way in both Hawaii and Queensland, Australia.[34] In Australia the plants treated were 10 to 12 months old and in from 6 to 8 weeks the application resulted in flowering. In Hawaii ethylene has been used as a means of extending the harvest period, which is usually short and intensive, over a longer period of time. In Australia the acetylene is applied as a saturated water solution into the heart of each plant or sucker where it is retained. Only a single application is necessary unless rain occurs within 24 hours. These materials have not been used for a similar purpose upon fruit plants in the United States.

Effect of water supply. A continuous reduction of soil moisture during the period in which the flowers are differentiated for the succeeding year's crop, produces an intensely stimulating effect upon flower formation.[1, 10, 38] In a number of irrigation experiments, apple trees in plots deprived of water, have produced the greatest number of flowers.[10] Thus as the vegetative growth is reduced, due to lack of water, a greater proportion of the buds, utilizing the released food substances, will then develop floral primordia. More than the usual number of flowers are differentiated upon the spurs and shoots of the apple, and, in addition, a great many flower buds are formed laterally upon shoots. Occasionally apple trees only three years old will differentiate flowers under these circumstances, an outcome otherwise delayed for several years. In the stone fruits also, especially the peach,[38] excessive flower-bud formation as a result of drouth conditions may become extremely exhaustive, unless provisions are made to decrease the load.

Water deficiency will not invariably induce flower formation. In case the deficiency is severe, the prevailing temperatures high, and the trees either bearing, or having previously borne heavy crops, flower production also will suffer from lack of water. Such circumstances result in excessive depletion of carbohydrates, since respiration is greatly increased by high temperature, while at the same time the rate of photosynthesis is considerably reduced by the water deficiency.[24] If, in addition, the trees must undergo a heavy demand upon carbohydrates, made by the developing fruits, the whole combination of factors working toward depletion of food materials will finally prevent flower production also.

Effect of application of nitrogen. Application of concentrated nitrogen-carrying fertilizers and manures, such as pig and hen manure, to young nonbearing fruit plants will definitely delay the formation of flowers. Such treatment only accelerates and maintains the rate of growth of shoots and spurs, leaves and stems, during a period when growth should have ceased and flower differentiation begun.[3] Excessive application of *inorganic* nitrogen fertilizer to young, nonbearing fruit plants tends to produce a similar though less pronounced effect. In bearing trees such an application, while it will not entirely prevent flower formation, may, under certain circumstances, reduce the proportion of buds containing flowers.[15]

On the other hand, when trees are low in vigor, a light or moderate nitrogen application tends to increase flower formation. Such a treatment, made in August, increased the rate of photosynthesis and, by delaying leaf fall, lengthened the period during which carbohydrates were formed.[22] As a result of this accumulation, the leaf surface might be somewhat increased during the following spring, thus favoring the differentiation of floral primordia.

Effect of pruning. The effect of pruning upon the formation of floral primordia depends, as does nitrogen fertilization, upon the severity of the treatment, as well as upon the age and condition of the plant. Pruning young, *nonbearing* fruit trees has resulted either in a delayed or a greatly reduced flower formation, a fact which is one of the outstanding results of pruning experiments with young trees. Even where the operation was only light to moderate, a proportionate delay in flower formation has nevertheless resulted. This stimulation of vigorous growth prevented spur formation in such varieties as Northern Spy which bears fruit on spurs alone. In view of these facts very light pruning of fruit trees before they come into bearing, is now standard practice in all fruit-growing regions of the United States. Dehorning of bearing peach trees results significantly in "blind nodes" and an immediate reduction of flower-bud formation.

On the other hand, pruning, provided it is not excessive, encourages flower formation on heavily bearing trees. Even excessive pruning has not entirely prevented flower formation, although the proportion of flower buds is reduced, due to the increase of vigorous, nonflowering shoots and water sprouts. This favorable effect on bearing trees can be assigned to a number of factors, the more important being: increased light, increased leaf size due to the release of additional water and nitrogen, and a reduction of the exhaustive effect of fruit production.

Effect of spray materials upon leaf functioning. Certain spray materials have been shown to have an unfavorable effect upon leaf functioning, particularly the rate of photosynthesis. While there are no quantitative data measuring the exact extent to which flower bud differentiation is reduced by spray materials, certain applications have, nevertheless, been shown to have a decidedly unfavorable effect upon the formation of carbohydrates. Liquid lime-sulfur solutions,[4; 25, 29] summer oils,[26] and to a less extent certain other spray materials have reduced the rate of photosynthesis despite the fact that no visible injury occurred to the leaves. Liquid lime-sulfur at the stronger dilution of 1 to 40 caused considerable reduction in photosynthesis, while at the weaker concentrations there was somewhat less effect. In general, wettable sulfur sprays, including flotation sulfur,[6, 29] ordinary dusting sulfur,[23] and Bordeaux mixture,[29] have resulted in little or no reduction in the rate of assimilation.

Temperature is a complicating factor. With an increase in temperature there is a tendency for greater reduction in photosynthesis for a given dilution of spray. Temperatures above 90° F. often result in a reduction in the photosynthetic activity following application of even the more dilute solutions.[4]

The results quoted above were obtained from leaves of the apple which showed no apparent burning. When injury to the leaf is so great as to be visible, the results are obviously more serious since the trend seems to be generally in the direction of decreased flower formation.

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4

SITE AND SOIL FOR THE FRUIT PLANTATION

While the variety must be considered the keystone of American fruit growing, no other factors are so important as the site and the soil. This has been stated so often that it sounds trite, yet experience confirms this observation so completely that it may be considered an axiom. Even slight deviations from the optimum site and soil may result in consistently lower yields. While all favorable factors are not necessarily associated together, and the "optimum" may not be easy to define, the student should be familiar with the factors involved.

The Location

Location usually refers to the geographical position or the place where the orchard is located in relation to some city, town, highway, or other convenient point of designation. This is in contrast to the term "site" which refers to the immediate place or situation; as elevation, relation to bodies of water, topography, and other factors having to do with the behavior of the trees themselves. The economic advantages of a location may outweigh those secured from a superior site and soil. Those who are near great centers of population have a distinct advantage over those who must ship long distances. The use of roadside or home markets to dispose of the crop, the advantages of good roads or other avenues of transportation, nearness to storage facilities and a source of water for spraying or irrigation, and orchard supplies are all of economic importance. But despite these obvious facts it is becoming less and less advisable to plant on any but the most desirable sites and soils because of the increasing importance of high average yields per tree or per acre.

There are often advantages in being located in a region where fruit growing is a common interest. Such a location enables one to keep informed on the best practices, time to spray, and the spray materials that are in vogue. Supplies and repairs to machinery are often more quickly and easily procured in a general fruit region. The washing and grading of fruit can often be done in a community or coöperative plant which gives a more uniform pack but is likely to be more expensive. Furthermore, a large fruit area attracts buyers of large quantities for the domestic and export market.

However, there are states where orchards are scattered and no large contiguous areas have been planted. Such situations will always exist and they have the advantage of somewhat independent, localized markets which may not obtain in a region of extensive plantings. Furthermore, there is not the disadvantage of an increased build-up of insect population such as codling moth in these districts.

Climate. The relation of climate to horticulture is very intimate and is almost the ultimate determinant of what shall be grown. The orchardist feels that he has reached the frontier of his knowledge and ingenuity in attempting to combat the elements and overcome their devastating effects.

Climate has been defined as the average condition of the atmosphere, while weather denotes a single occurrence, or event, in the series of conditions that make up climate. The climate of a place is, then, in a sense its average weather. Phenology is the science of the relations between climate and periodic biological phenomena, such as flowering, leafing, and fruiting of plants.

The particular natural phenomena constituting climate that are of special interest in this connection are temperature, rainfall, wind, sunlight, frost, hail, and humidity. These features of weather may specifically affect the fruit crop for any given season in two general ways: (1) it may govern largely the potential possibilities of the trees to form flower buds; and (2) it may partially or entirely destroy the buds, blossoms, or crop in the process of development. In addition, the growth of the tree may be affected, and injuries from low winter temperatures occur.

Temperature. This is the most important climatic factor affecting the distribution of plant species and is the ultimate determiner of the type of fruit growing, both in the temperate and subtropical zones, although water supply is very close to temperature in this connection. The annual cumulation temperature of the air must be considered in studying the temperature effect on vegetation. There is a minimum and maximum temperature, below or above which the plant does not function, and there is for each kind of plant an optimum temperature at which it grows or functions best. The minimum for most higher plants is around 40° F. to 43° F., while the optimum ranges from 75° F. to 85° F., depending on the species and to some extent the variety. Since the various processes of the plant may have different optima, the above temperatures should be considered as applying particularly to the more manifest growth activities.

Many fruit sections are accumulating data on which future plantings may be based with greater intelligence. The mean annual temperature or the mean of the 365 successive daily means is a figure of importance for any given place, as is also the mean temperature of the hottest 6 weeks. The annual mean is frequently computed from the twelve monthly means which is practically the same as when calculated on the daily basis. The average dates of the last frost in spring and the first frost in autumn, as well as the winter minimum and summer maximum are also of great importance to the pomologist. From the former figures is calculated the average number of days free from frost at any particular point, and hence the length of the average growing season.

Rainfall. The chief interest of the orchardist in rainfall is that of securing a water supply for satisfactory growth of the trees and the crop of fruit, and in some cases in a supply of water for spraying. Most sections are likely to suffer at times from droughty conditions, and this situation has become acute in many areas during the period since 1930. The relation of fruit production and moisture supply is treated elsewhere.

From the eastern margin of the Great Plains, where the annual rainfall is about 20 inches, to the Atlantic Ocean and southward to the Gulf of Mexico, there is usually sufficient rainfall for agricultural purposes and only in a few limited areas is irrigation practiced in orchards. Disregarding local areas on the mountains, the annual rainfall is greatest (50 inches) towards the Gulf and on the South Atlantic coast, and decreases from about 40 to 45 inches over much of the north and central Atlantic coast and Ohio Valley to 30 to 40 inches over the prairies and 20 inches at about the 100th meridian.

In the Plains region rainfall decreases from over 30 inches on the eastern margin to 15 inches on the western, and where the rainfall is below 20 inches it is insufficient for fruit crops, and irrigation must be practiced.

In the great interior region known as the Plateau Province, the mean annual rainfall is everywhere less than 20 inches; it is mostly below 10 inches, and over no insignificant portion of the Southwest it is even below 5 inches.

Over the narrow Pacific coastal belt, climatic conditions are quite unlike those elsewhere in the country, and in many respects resemble those of northwestern and western Europe, including the Mediterranean area. The wide range of latitude between north and south, together with the varying topographical controls and the differences in exposure to the ocean influences, explain the great variety of climate in this province. The range varies from the rainy and densely forested slopes of Washington to semiarid southern California; from the lowlands to the snow-covered mountain tops; from the cool summer of the coast to the hot summers of the Great Valley. The rainfall is heavy (100 inches) on the northwestern coast of Washington, and decreases rapidly to the south, to about 10 inches in the San Joaquin Valley.

Never in the history of American agriculture has so much attention been given to means of conserving moisture and providing for the prevention of runoff of rainfall, as during the past few years.

Winds. Heavy winds also play a part in the weather conditions that affect fruit growing. They are by no means such a destructive agent as temperature, but they may reduce the number of blossoms which set fruit and prove ruinous to the crop as it approaches the harvesting season.

The effect of wind on the maturing crop of fruit is a constant source of loss, as more or less fruit is blown from the trees every year, and in some seasons it assumes serious proportions. Windbreaks and close planting of the trees on the windward side are often used to reduce the damage.

Winds, in some sections, cause young trees to grow one-sided and to lean to the leeward, but it would be difficult to estimate the actual damage.

One of the most serious effects of wind is that encountered during the spraying (or dusting) season. Not infrequently that work must be delayed on account of high winds until the fruit crop is jeopardized.

Sunshine. Just as rain is the most unfavorable element in preventing pollination, so conversely is sunshine most favorable to it, especially when accompanied by a relatively low percentage of humidity. This set of conditions affords the best opportunity for the agencies of pollination and also for the growth of the pollen tube.

Sunshine is of prime importance in the growth of plants in general and in the development and coloring of fruit. Emphasis should be placed on the great importance of sunshine or light intensity in the rate of photosynthesis. It is not improbable that the heavy production of fruit in the arid western districts may be accounted for by the intensity of light under those conditions. The effect of shade in preventing flower-bud formation is also worthy of note.

Spring frosts. Frosts in autumn are of some economic importance to the fruit grower, but those occurring in the spring are usually much more disastrous to the fruit crop. The destruction of blossoms and hence the prospective crop by spring frosts either locally or over rather large areas is a common occurrence and one of the most ruinous phases of fruit growing.

The United States Weather Bureau distinguishes three types of frost, based on the degree or severity of it; namely, light, heavy, and killing. The latter two are usually distinguished by the extent of injury to vegetation rather than to the actual amount of deposit. The term "killing frost" is described as one which is generally destructive to the staple products of the locality. Vegetation may also be damaged by low temperature without an actual deposit of frost, a condition due usually to cloudiness. The probable dates of killing frosts for any locality are a valuable guide to the fruit grower and gardener, and some maps have been prepared by the Weather Bureau showing the dates of the last killing frost in spring, for the first in fall, and for the average number of days without killing frosts.[1]

While one may attempt to determine places that are comparatively immune by computing the average date of the last killing frost, yet it must be realized that in favorable locations there may occasionally be destructive frosts. For instance, it is not necessary to have a crop of peaches or sweet cherries every year in order to make the venture profitable.

Frost injury may take the form of russeting the fruit, occurring either in bands, in patches about the basin or cavity, or in spots on the surface of the skin. It may also cause blistering of the young leaves when they first expand, in which case they do not fully develop and may or may not fall prematurely. In addition to the destruction of the pistils of the flowers, the stems and adjacent tissue may be injured, which often results in a heavy drop of fruit.

Hail. Hail usually occurs during the summer and usually during a thunder storm. The area of most frequent occurrence is in the western Middlewest although there is a wide range of incidence. Hail may cause serious loss in the orchard as well as to farm crops. Hail marks on the fruit injure its selling quality, and indeed may break open the skin, thus encouraging rapid deterioration. Aside from frost there is no element of the weather that can so quickly destroy a crop of fruit.

Serious injury may also occur to the tree itself, the healed scars somewhat resembling the work of the tree cricket (*Oecanthus* sp.) or cicada (*Tibicen septendecim*).

The Site

The commercial orchard represents a long-time investment, and consideration should be given to all of the factors involved in a desirable site. The chief ones are soil and topography, and without a favorable combination of them orcharding is hazardous. Fortunately there are more favorable sites than will ever be needed for this branch of agriculture, and it is unfortunate indeed that so many orchards have been planted on what may be termed marginal or submarginal sites. In other words, skill in management cannot offset the disadvantages of low yields, high cost of production, poor color, low quality, and the loss of trees themselves, which is part of the capital investment.

Ecology is a study of the adaptation of plants to their entire environment. Seeking an orchard site is practically an effort to find a place where not only the kind of fruit but also the varieties will be best adapted to their enivronment. Much more yet needs to be done in America in the study of "land use" or the suitability of crops to the location where they are to be grown.

Topography. This feature deals with the exact delineation and description in minute detail of a place or region. In horticulture it is used more roughly to describe the contour of the land, its elevation or depression, and other features of the terrain.

Topography is of special interest from the standpoint of erosion, frost, and freezing hazards. Also the susceptibility to russeting of fruit, to spray injury, and the ease or difficulty of orchard operations are involved in the topography of the land. The best sites are those on broad ridges or upland plains bordering depressions, or lacking these features, they may be near large bodies of water, assuming in all cases a favorable soil situation.

Usually it is considered that elevation above sea level is not so important as that above the immediately surrounding country. Difference in elevation which seems comparatively slight may be sufficient to make the higher land the more profitable. For this reason it would be desirable to keep maximum and minimum thermometers at different points on the proposed area (especially during springtime) before a site is selected.

The importance of slope or exposure can be overestimated. Toward the southern zones of fruit growing, a southern exposure may result in early blossoming, but farther north this is not an important factor.

The gradient of the slope is an important factor in the evaluation of an orchard site, but has to do more particularly with cultivation, ease of moving heavy equipment through the orchard, and hauling the fruit crop. The degree of slope which is subject to serious erosion under cultivation varies with the kind of soil, but in general it is impracticable to cultivate any land having slopes of 15 per cent or more, and poor growth is frequently observed on slopes of no more than 4 per cent where clean cultivation is practiced. This will be referred to under Laying Out and Planting the Orchard. It should not be inferred that other systems of culture are not practical with slopes of greater than 15 per cent.

Air drainage. As a result of the factors associated with elevation or topography it has become axiomatic in fruit growing to plant orchards on elevations and to avoid valleys, coves, or other places where the movement of air is restricted. This doctrine is based on the fact that cold air drains from high lands into valleys and often results in damage to crops in the latter places while those on higher elevations may escape injury. While it is true that the air temperature becomes lower with increasing elevation, yet during clear nights there is a temperature inversion.

The facts here would seem to be contradictory, for there is a vertical decrease of temperature with the increase in elevation, amounting to about 1° F. for every 300 feet. The amount of decrease of temperature will vary with the latitude, exposure, season, and local conditions. But what is termed "inversions of temperature" occur in clear cool nights up to a certain elevation which results in the higher lands being warmer than the valleys. According to Hann,[8] "This increase of temperature upward reaches altitudes of at least 300 m., and is rapid in the lower strata, but slower farther up." In this country the effect of these inversions of temperature are experienced at practically all elevations at which fruit is grown, except in certain canyons in the Western States where "draws" of air offset the effects.

This occurrence of colder temperature in valleys is explained by the fact that there is a radiation of heat from the earth during the night and as a result the earth is cooled. The stratum of air which lies next to the earth is cooler, and, as cold air is heavier than warm, it results in its flowing downward, and the warm air of the valley rising. Air will also lie in strata of somewhat equal temperatures, which phenomenon is experienced in traveling over undulating country, particularly at night. As a result, not only are blossoms or fruits at lower elevations often destroyed when those at higher ones are unhurt, but often those on the lower part of a tree at a certain altitude are destroyed and those in the upper part unhurt.

Effect of bodies of water. In lieu of a site whose elevation above surrounding country is a feature, one near a large body of water is a good substitute, and in some cases even better. Such a site usually experiences slow changes of temperature due to the very great specific heat of water. It requires about nine times as much heat to warm a gram of water 1 degree as to warm a similar quantity of iron and more than four times as much as to warm a gram of air 1 degree. Land on the leeward side of a body of water experiences higher winter temperatures than the windward side and as a consequence flower buds are held back by the cold winds in spring, so that frosts rarely destroy the blossoms.

One of the best-known and in some respects most unique cases of the effect of water on climate is seen in the Michigan fruit belt. This is a strip of land from 10 to 20 miles in width along the west side of the state from the Indiana line nearly to the Straits of Mackinac. The southern boundary of this belt is about 42° N. latitude while the northern boundary is almost 46°, and in this belt are extensively grown such tender fruits as the peach and cherry. The tempered effect along this littoral region is due to the prevailing winds passing over Lake Michigan during most of the winter and spring months. In the spring the winds are kept continually cool in passing over the lake and hence prevent unseasonable advancement of the buds in April and May. On the other hand, the winter winds that leave the Wisconsin shore at a temperature of 30 to 40 degrees below zero arrive on the Michigan side at a temperature of little if any below zero, since the waters of the lake rarely freeze over and are commonly some 3 to 5 degrees above the freezing point.

Along the shores of Lakes Erie, Ontario, and other smaller lakes there are considerable plantings of fruits of all kinds. In those cases the influence of the water does not extend very far but varies in different years. But an acre of orchard located within a couple of miles of such a body of water may be worth several acres farther back.

The principal fruit district of western New York is a belt 6 to 10 miles wide extending along the lake shore from Buffalo, on Lake Erie, to Oswego, on Lake Ontario, a distance of about 125 miles. The important factor here is climate, as well as some deep, well-drained soils. At Rochester the mean annual temperature is 47° F., and the absolute minimum is −30° and at Cooperstown, about 100 miles from the lake, −33°. At Rochester the average date of the last killing frost in spring is April 29, at Cooperstown it is May 5, and at Cortland, May 15. That this difference in climate within a narrow range has a profound influence on fruit growing is evident.

Protection from frost. A number of devices have been used to protect fruit plantations from frost. The production of a smudge of smoke is not sufficient for the purpose unless enough heat is liberated to raise the temperature of the orchard air. Neither have sprays with water proven practical on an orchard scale. The forced circulation of air by airplane or large propeller fans has been reported in some quarters (California, New Zealand), but favorable results have not been accomplished.[15, 20]

The oil heater seems to be as effective as any method but has the nuisance of smoke and soot. Low stack oil heaters seem to eliminate this and at a reasonable cost. Hot air (central heating) has proven costly to install but cheap and clean to run. Of solid fuels petroleum coke briquettes have been satisfactory.

Windbreaks. It has been customary in many sections to plant a windbreak on the windward side of an orchard for protection. Frequently the windbreaks are too close to the fruit trees and result in more damage than they prevent. When the wind passes over a windbreak it leaves an area of still air on the leeward side for some distance from it. It is in this area that the greatest frost or freezing damage is done. This has been frequently noticed with grapes, strawberries, peaches, apples, and, in fact, all sorts of fruit crops. The same is true where a piece of woodland serves as a windbreak. Even if such a woodlot is on the leeward side of the orchard, particularly at the base of a slope, the cold air drains into this pocket and is held there resulting in more damage to fruit trees than elsewhere in the orchard.

A windbreak may also result in serious shade and in competition for soil moisture and nutrients, both of which are unfavorable to growth and yield of trees. Likewise it may be an ideal place for the harboring of injurious insects and diseases.

The Soil

No student of plant life can ignore the medium in which the plant grows. This medium in most cases is soil. Yet the most casual observation shows that soils vary in their nature or physical makeup and that plants flourish differently on different types. What constitutes a productive and what an unproductive soil? Why do fruit trees thrive differently on the same soil during dry and wet periods? The answers to such questions would seem to involve the inherent nature or physical structure of the soil as well as its chemical composition.

Soil defined. The soil is a very complex system made up of decaying organic matter and weathering or weathered rock fragments in varying proportions, which, when supplied with air and water, will support plant growth.

The development of a soil is largely controlled by its environmental conditions. Since these conditions are not static, and since they vary widely over relatively small areas, a wide variety of soils exists. Ever-changing forces of climate and local conditions leave certain definite characteristics by which a soil may be identified.

Soils which are derived from parent material over which they lie are known as residual soils. The parent rock gradually disintegrates, and the surface becomes a different material from that below. For instance, a soil derived from limestone may have an acid reaction. This surface material often attains a thickness of several feet and, as has been mentioned, has certain definite inherent characteristics. Examination shows usually definite layers, the thickness depending on the environmental conditions.

A typical soil in the orchard regions usually consists of three distinct layers. The top one is designated as the A horizon, and is the most completely weathered portion from which materials have been removed by leaching. The B horizon just beneath is less weathered and is accumulating materials leached from the A horizon. The C horizon consists of the parent material in an unweathered or partially weathered condition. Each of these horizons is further divided into subhorizons, *viz.*, A_1, A_2; B_1, B_2; C_1, C_2. These horizons make up what is known as the soil profile and this constitutes the basis on which soils are classified and mapped. The top layer of soil is usually the most fertile one and the one best adapted for cultivation. When it is removed by erosion, the value of the land is greatly reduced.

All soils, however, are not of a residual nature and do not conform to this classification. Some which are not formed from the material over which they lie include glacial and moraine soils, water deposits, and wind-blown soils. Other factors which influence the profile are erosion and drainage.

An orchard soil. It is not possible or desirable to enter into a full discussion of soil properties in this connection, but some phases are inescapable if the orchardist is to be well informed. Furthermore, not all of the problems involved seem to be well understood at present. Certain of the soil factors affecting the moisture supply of the plant are discussed in Chapter 8.

Fortunately, both fruit trees and small fruits thrive over a wide range of soil types and the limits are not so exacting as with some other crops, however, experience indicates that soil alone may often cause a 50 to 100 per cent difference in yield. A survey of orchard soil in Quebec[18] showed what has frequently been observed; namely, that a very productive soil for farm crops may not be suitable for orchards and conversely, a less productive one in good physical condition may support excellent apple trees when properly fertilized and managed. For instance, the Champlain soils are very fertile but the natural drainage of these heavy soils is not good and apple trees, as a rule, are short-lived.

Soil color. Another characteristic that is commonly used in identifying favorable and unfavorable orchard soils is that of color.

Soils vary in color considerably, the most usual being black, gray, brown, yellow, and red. Soils vary in color depending upon the amount of organic matter present, the state of hydration or oxidation of the iron compound, and the moisture content.

When examining a soil for its possible adaptability for fruit growing, its color should be noted as this gives an excellent index of its depth of drainage. Poor subsurface drainage results in inadequate aeration which causes mottling in the subsoil. These mottled colors are most usually brown and gray, yellow and gray, or yellow and brown. Various shades of these color combinations might be present. The depth of mottling corresponds to the depth of good subsurface drainage. If mottling occurs near the surface such soils are usually too poorly drained for a good orchard site. The best method to study subsoil colors would be to dig a trench some two feet wide, several feet long, and about six feet deep. The whole profile can be readily seen in this way. This may seem like considerable effort but when it is remembered that an orchard is a long-time investment every means should be used to insure its success. A simpler method is that of the soil auger, particularly the California soil tube, whereby a continuous core of soil can be removed.

There are many variations of color as well as pockets which vary markedly within close proximity. Oskamp and Batjer [13] described four distinct types of profile from the standpoint of color which they consider were clearly related to drainage conditions and tree performance, and which may be taken as a guide.

Uniform brown profile: Comparatively uniform in color, texture, and structure to a depth of several feet, with but slight development of horizons. This was designated as the "best-drained series" in the soil classification. (Fig. 33.) [14]

Slightly mottled profile: Horizons more definite, with moderate mottling and some compaction in the upper subsoil, but the differences in color are not striking, being primarily variations in shade. A well-pronounced gray layer is absent. The texture may increase in heaviness with depth. This was designated as the "well-drained series."

Gray layer profile: Horizons sharply defined, with a well-developed "gray layer." Pronounced mottling and a heavy subsoil are characteristic. This has been designated as the "imperfectly drained series."

Black-gray profile: Horizons the most sharply defined of all, the gray layer usually being thick and continuous, and the topsoil being much darker in color than in the associated series. This is the prevailing profile of basin-like areas and was designated as the "Depressional group," all soils in which have poor natural drainage and are not adapted to fruit growing. (Fig. 34.)

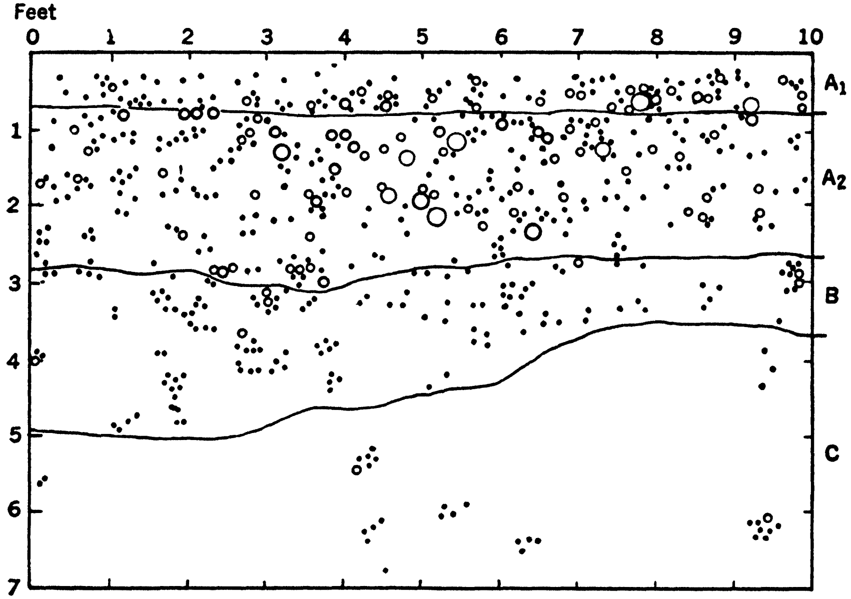

FIG. 33. Root distribution on Alton gravelly loam. A_1, brown gravelly sandy loam; A_2, brownish yellow sandy loam; B, waterworn sandstone and gravel embedded in reddish brown sand; C, gray sand, loose. Satisfactory rooting in a uniform brown profile. The different sizes of circles represent approximate root diameters as follows: black dot 0–2 mm, smallest light circle 2–5 mm, next larger heavy circle 5–10 mm, next larger light circle 10–20 mm, and so on, in gradations of 10 mm, the circles being alternately heavy and light.

Ground water table. While varying from season to season, it has been found useful to determine the ground water table in attempting to select an orchard site. This is done by making a well 4 feet deep with a soil auger and dropping into it a galvanized iron tube ⅝ inch in diameter and 4 feet long. The tube used by Oskamp [10] was a piece of 28 gauge sheet iron rolled into the form of a pipe so that the edges lapped slightly. A convenient method is also to use drain tiles, one superimposed on another. By means of a post hole digger the hole can be made and three or four 1-foot tiles placed one above the other. Four such test wells per acre well distributed over the proposed site are better than a lesser number. The height of the water table is then recorded throughout a season particularly during April and May and after rains. "The important thing is the depth to which water is able to recede within a few days after a rain. Some good fruit soils fill with ground water to within a few inches of the surface after very heavy rains, but in the course of an hour or two the water falls rapidly and in a day or two will be back nearly to the level obtaining before the rain. Readings could well be taken at 3-day intervals." [10] If ground water persists within a foot or two of the surface during the critical blossoming and fruit setting period, many roots will die and the tree suffers accordingly. Well-drained soils contain almost no ground (free) water in the surface 4 feet except shortly after a rain; imperfectly drained ones will have ground water at about the 2-foot level for a month or more in May and June, while the poorest drained soils will be waterlogged within a foot of the surface.

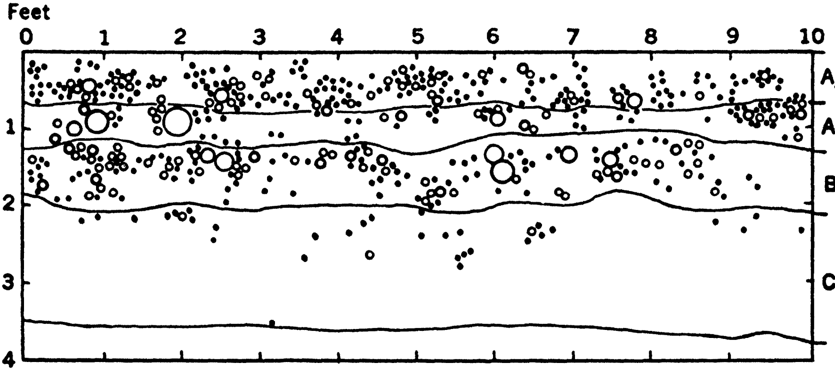

FIG. 34. Root distribution on Lockport loam. A_1, reddish brown loam, firm; A_2, ash-gray sandy loam, compact; B, Indian-red silt loam, very compact; C, Indian-red and brown very compact and gravelly soil mass, with pockets of clay. The trees on this soil are the most shallow-rooted of those on any soil studied in this area. The different sizes of circles represent approximate root diameters as follows: black dot 0–2 mm, smallest light circle 2–5 mm, next larger heavy circle 5–10 mm, next larger light circle 10–20 mm, and so on, in gradations of 10 mm, the circles being alternately heavy and light.

A close correlation between depth to ground water and yield was found in New York state. It is a relatively simple determination and apparently a useful tool in selecting orchard sites.

Mechanical classification. Soils are, as has been mentioned, made up of organic matter and particles of parent material. The size of these particles vary from coarse sand and gravel to particles so small that they may not even be seen with a microscope. These small particles constitute clay. The intermediate sized particles, between sand and clay, are known as silt. Soils are classified on the basis of the relative amounts of these particles present. A sand has less than 20 per cent silt and clay. A loam contains 20 per cent or less of clay, 50 per cent or more of silt, and 30 to 50 per cent of sand. A clay contains at least 30 per cent of the clay particles and 70 per cent or less of other material.

Sand is a valuable component of an orchard soil in that it lightens the soil, gives it natural drainage, and has a tendency to make it "warm."

Clay forms to a considerable extent the body of the soil. It is derived from various rocks and carries considerable of the mineral elements. The colloids of the soil, which have received considerable attention, are associated with the finer clay particles. If clay is present in abundance, the soil will dry badly, shrink, and crack during dry periods. Clay also causes the soil to be "heavy" and difficult to work when wet.

Humus, as discussed elsewhere, is a term given to decomposed vegetation. This term is often used loosely or incorrectly, since vegetation plowed into the soil does not become humus until it is thoroughly decayed. The humic acids produced during decay contribute materially to making nutrients available to plants.

The term loam is used to describe a soil made up of a combination of sand, silt, and clay and it is further defined by the predominance of one or the other, as sandy loam, silt loam, or clay loam. When clay and silt particles predominate, only the fine grades of sand are usually present. If the silt grade is most abundant, the soil is a silt loam. If clay is greatest in amount, the soil is a clay loam. A soil containing as much as 50 per cent of clay is very "heavy," while those containing 60 to 70 per cent, as at Medford, Oregon, are exceedingly stiff and hard to work (adobe).

Aeration of soils. Out of wide experience orchardists have come to believe that a compact soil is unfavorable and anything that adds to extreme compacting should be avoided. This view is supported by investigational work in a number of places. When it is remembered that about 50 per cent of the average soil volume is pore space the importance of aeration can be appreciated. Under optimum conditions for plant growth about half of this pore space should be occupied by water and the rest by air. There is always a reciprocal relation between the volume occupied by the water and that occupied by the air. In compact soils the pores are very small and are filled with water and air is excluded. If for any reason water enters the soil faster than it can percolate through, the air in the pore spaces may be completely replaced by water, producing what is commonly called a water-logged soil, according to Bradfield.

It has been estimated from the amount of CO_2 produced in a square meter of the average soil in one day (average 7 liters) that there must be a complete change in the soil air to a depth of 20 cm. every hour in order to maintain the soil air at its average composition. Since fruit trees appear to belong to a group of economic plants that require a large amount of oxygen in the soil air, it can be seen that even a partial water-logging or an extreme compactness of the soil would interfere with their normal functioning.[4]

In the elaborate soil studies in New York, Oskamp and Batjer conclude that "Certainly, under the conditions of these studies, the limiting factor in orchard production is drainage rather than fertility." [13]

Root distribution. It has been learned that the extent and depth of the root system of a tree has an important bearing upon its productiveness and length of life. The distribution of roots is largely a matter of the character of soil in which the tree grows. If the roots grow only near the surface and are confined to a small area, the tree is subject to drought, has inadequate support, and does not have available as large a supply of nutrients as it would have had if the roots had a greater distribution. Data have been collected to show that on shallow soils, under most conditions, fruit growing is not so profitable as though the trees had been able to root more deeply.

It is understood, of course, that fruits vary in their natural ability to root deeply. Different varieties of the same fruit may respond differently. The kind of understock is also important in this respect. Other factors which influence root distribution are, improper aeration (too much or too little), high water table, faulty drainage, and the properties of the soil profile such as inadequate aeration, the presence of a clay pan, or coarsely textured layers.

Soil type and root penetration. It will be understood that a plant has no volition in the matter of "seeking" water, air, etc., but that the roots grow in a favorable medium. The character of the subsoil is one of the most important factors influencing the depth of rooting.

The charts of root distribution of apple trees in New York state, one on a favorable and one on an unfavorable soil, already referred to, show the wide difference which may exist in the root systems of trees on different soils.[14] In the one type the roots did not penetrate in excess of 3 feet. (Fig. 34.) The soil type which gave the best returns was one with a loose, open subsoil, into which the roots penetrated to 9 feet.

Sweet,[19] also working in western New York, noted that many orchards are planted on soil where the maximum depth of rooting is 3 feet. In other sections of imperfectly drained soil it is about 6 feet, but in the deepest best-drained soils it is more than 9 feet. He found that "trees which, by deep and extensive rooting, have the greatest soil and moisture resources give the largest and most consistent yields, and fruit of the best quality."

In Oklahoma it was found that roots of apple and apricot trees on a heavy silt loam were limited to the upper 27 inches and that under those conditions the trees did not produce well and died prematurely.[6]

In Oregon [16] it was determined that the variety or kind of fruit did not enter into the depth of rooting so much as did the soil type. Soils which permitted a rooting of 6 feet were profitable, but where less than that only marginal returns were obtained. The best soils permitted rooting to a depth of 8 to 10 feet.

Schuster [16] found that there was no correlation between the amount of water that can be stored in a soil and the amount that can be used by plants. Some of the soils which held the largest amount of water were among the most droughty. He found loganberry roots at 10½ feet and filbert at 11½ feet so that he concluded that most plants would root deeply if not prevented by some inhibiting factor in the soil.

He further observes that "the depth to which roots can penetrate is the actual depth of a soil so far as tree growth is concerned. No matter how much farther it is easy to dig or bore, if tree roots cannot enter and withdraw moisture or nutrients from this lower level, the reserve supply of the deep soil is of no value to the tree. . . . A deep, well-aerated, fertile soil to begin with is the real solution of the problem."

With grapes Oskamp [11] found the average horizontal extension of roots in a mature vineyard to be 8 to 12 feet from the trunk, with some roots penetrating to 15 feet and a few to 20 feet. The usual depth of rooting on the Dunkirk gravelly loam was 5 to 6 feet, while some rooted as deep as 10 feet. This soil seemed to be ideal for grapes because of extensive root development rather than the fertility or moisture-holding capacity of the soil.

Cultural practices and root distribution. Since the rooting of trees is under consideration at this point, the relationship of culture as well as soil may be mentioned.

Probably the most striking effect of a cultural method is that of mulching trees. Beneath the mulch there appears to be a most favorable situation for root growth, and not infrequently there will be a thick mat of roots in the uppermost layer of soil, on top of the ground, and extending throughout the decaying vegetation. So thick do the roots become in the organic material that they cannot be separated from it. Under the Ohio conditions studied, however, this has not influenced the deep rooting of the trees also if the subsoil was favorable. In fact, there was no consistent difference in depth of rooting between the mulched and cultivated trees. The largest number was near the surface of the ground and the bole of the tree and they gradually diminished outward and downward. The roots of apple trees set 40 feet apart were more than meeting at twelve years of age.[3, 7, 19]

In contrast with these results those in Nebraska showed that under straw mulch the roots had a pronounced shallow, lateral development and under sod mulch both tops and roots were dwarfed. Under clean culture the roots penetrated deeply and spread widely in such a manner that a very large volume of soil was thoroughly occupied. "The response of the root systems to the various cultural treatments can be explained largely on the basis of the water content and its location in the soil. . . . After three years of growth, apple trees on loess soil had absorbed about one-half the total available moisture present in the soil directly beneath the trees to a depth of 9 feet." It was thought that the difference in response of roots to various cultural treatments was largely due to differences of soil moisture.[21]

Soil reaction. Fruit trees are tolerant of a wide range of soil reactions as compared with many other crop plants. Apples, for instance, are reported as thriving on soils with a reaction that is quite acid, about pH 4 to one that is alkaline, pH 8.5 (pH 7.0 being neutral). There is a wide range with other fruits also but the exact status for each has not been determined, some writers having arbitrarily placed the optimum value at pH 5.5. To what extent varieties of the different fruits vary in their sensitivity to acidity and alkalinity has not been established, but minor variations seem to occur.

Usually there is a fairly close relationship between the pH value and the calcium content of the soil, since calcium accounts for about 80 per cent of the reaction value of the exchangeable bases in soils. This is not necessarily true, however. A soil may be deficient in calcium although it does not have a low pH value. This may be due to the presence of bases other than calcium or to a low base adsorption power of the soil. Such deficiencies have been reported for sandy soils in the Coastal Plain regions. This fact is of much less importance in orcharding than with certain other crops since orchard trees have rarely responded to applications of lime. Poor drainage within the soil is likely to be the true cause of difficulty rather than a given pH value.

It is quite a different question where the cover or intercrops are concerned, for frequently they will respond notably to liming and thus indirectly the trees may benefit.

The most common materials used to decrease soil acidity are calcium hydroxide (hydrated lime), calcium carbonate (ground limestone), and calcium oxide (quicklime). The effectiveness of a material depends largely on its solubility, fineness to which it is ground, and the inherent properties of the material itself. Likewise the soil itself exerts an influence, depending in part upon its colloidal content. Soils containing considerable amounts of clay or organic matter will require a larger amount of material to change the reaction a given amount than will sandy soils. There is also a relationship between pH value and the amount or availability of certain nutrient elements as well as toxicity of certain elements. Likewise bacterial activity may be affected.

Recently the tendency has been to place more emphasis on total bases in the soil rather than on the soil reaction. The amount of total bases probably gives a more complete picture of conditions as they exist in the soil. Merely to determine the pH of an orchard soil gives less useful information than has often been assumed. For instance, it has been reported that the growth and production of apple trees was not influenced by a change in soil reaction of 2.3 pH units when brought about by different soil treatments.[2] Work in Ohio showed clearly that a change in reaction of the surface soil of about 1.5 pH units did not affect tree growth or production.

There has been found to be a correlation between depth to ground water and pH value, also. Where drainage is slow there is less rapid leaching of the basic elements, and this results in a higher pH value.

Effect of fertilizers on soil reaction. Fertilizers are sometimes offered to orchardists because of their implied effect upon the acidity of the soil and others are avoided for the same reason. Calcium, magnesium, and sodium are basic elements frequently found in fertilizers, whereas sulfate is the radical most frequently responsible for acidity.

But the effect of fertilizers on soil reaction is greatest usually in the surface few inches. Sulfate of ammonia has been found to influence slightly the pH value of a soil to as great a depth as 12 inches, although this is extreme and a depth of 4 to 6 inches would be more characteristic on loam or clay soils. The influence would not be expected below a few inches until the greater portion of active bases had been removed. Thus on soils of a high exchange complex it would be expected that the effect would be noted only at the surface. Fertilizers with an alkaline reaction would exhibit their effect only at the surface, since the large exchange complex would tie up the basic elements in that region.

In Fig. 35 is shown the influence of calcium cyanamid and sulfate of ammonia on an Ohio orchard soil after 6 years of treatment.

Work at the Ohio Station shows that the effect of sulfate of ammonia does not extend appreciably into the root zone. The figures for the depths of 4 to 8 inches, and 8 to 16 inches showed no significant differences between plots. Differences in pH values between samples in the same plot were greater than differences between plots at these greater depths.

A somewhat different situation is reported on a Frankstown silt loam soil in West Virginia.[2] Where 4 pounds of nitrate of soda and 3 pounds of sulfate of ammonia respectively had been applied to apple trees for a period of 11 years the influence was marked and consistent. The pH of the soil treated with nitrate of soda was higher on an average of 2.3 units in the upper 5 inches, while the 16- to 20-inch samples showed a difference of 0.4 pH. Since no check plots are recorded it cannot be definitely stated to what degree the sodium raised the pH at lower levels and to what extent the increased acidity was due to the sulfate.

The effect of these two materials on root growth was striking. "In at least half of the pairs, the root weights of the nitrated trees were more than double that of the trees receiving sulfate. In only a few instances were the increases in amounts less than 50 per cent."

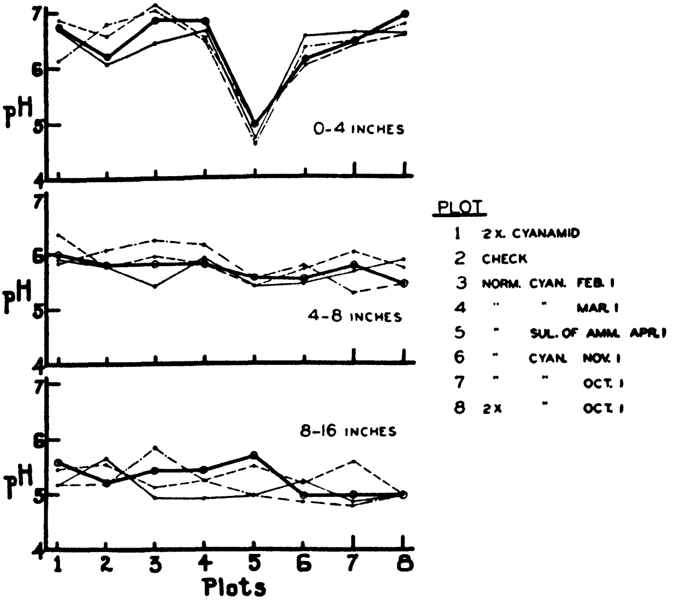

FIG. 35. Applications of Cyanamid and sulfate of ammonia were begun in an apple orchard in a Wooster silt loam soil in 1931. In 1938 pH determinations were made to determine the effect of the treatments on the soil reaction. It will be noted that sulfate of ammonia has lowered the pH from about 6.5 to 5.0 or lower in the surface four inches but has not affected it to a lower depth.

There were no significant differences in top growth or yield between the plots, for which no explanation seems available.

Soil Requirements of Fruit Plants

Some of the soil factors associated with fruit production have been discussed, and the special soil requirements of some of the leading fruits may now be mentioned. These have been presented in the *U. S. Yearbook of Agriculture* and the following suggestions are taken from that source.[9]

Apple. There are special varietal considerations with the apple. Thus, the Rhode Island Greening appears better suited to rich, heavy soils than the Baldwin. Most of the apple acreage is found in the eastern and northern parts of the United States where the summers are comparatively cool and the winters are less severe than in the interior of the continent. These include the Hudson River Valley section and the Lake Ontario plain of New York; the limestone valleys of Virginia, Maryland, and Pennsylvania; sections of New England; the western Michigan area; the western Illinois district; and the Ozark region.

Although most of the apple acreage is in the East, the most important individual apple-producing areas from the point of view of intensity of production are the Wenatchee and Yakima Valleys of Washington. Other areas of the West that are irrigated or receive supplementary irrigation, are the Hood River Valley in Oregon; the Payette-Weiser area, Idaho; the Grand Junction-Delta-Montrose district, Colorado; and the Sebastopol and Watsonville districts, California.

Among the many soils that are used for apples throughout the country, the following are distinctly important: The Dunkirk of the Ontario district; the Dutchess of the Hudson Valley; the Frederick, Frankstown, and Murrill, of the limestone valleys; the Isabella, Miami, and the Hillsdale loams of Michigan; the Baxter and Clarksville soils of northwestern Arkansas and southwestern Missouri; the Wind River loam of the Hood River Valley; the Wenatchee loam of Washington.

Pear. In general, pears appear better adapted to somewhat heavier soils than other orchard trees. However, adequate depth of soil suitable for root development, with good drainage and aeration, is especially important. Excessive available fertility, particularly with respect to nitrogen, is to be avoided from the standpoint of blight injury. Frequently it is best to maintain the trees in sod with only moderate applications of nitrogen.

The following soils have been found desirable in important areas of pear production: Hudson silty clay loam of the Hudson Valley, New York; Darien and Collamer silty clay loams of western New York; Napanee silt loam of Michigan; Gibson silt loam of southern Indiana and Illinois; Medford gravelly clay loam of Oregon; and Aiken silty clay loam of California.

Peach. This crop is most commonly grown on soils of somewhat lighter texture than is considered most desirable for apples, although the best apple soils are also suitable for peaches, within their climatic limitations. The following are typical of important peach sections: Palmyra and Alton gravelly sandy loams of western New York; Manchester gravelly sandy loam of Connecticut; Norfolk sand of North Carolina; Greenville sandy loam of Georgia; Fox sandy loam of Michigan; Tujunga sand, irrigated, and Yolo fine sandy loam of California.

Plum. The soil requirements for plums appear to be similar to those for pears. In California, where the prune types are most extensively grown, the Yolo silt loam is typical of a highly productive prune soil.

Cherry. Cherries require less moisture than apples and are frequently grown on soils of light texture. Deep, dry sands are objectionable, however, except in a few instances where water may easily be supplied in plentiful amounts. The following soils are especially productive in important centers of production: Dunkirk and Alton sandy loams of western New York; Roselawn loamy sand of Michigan; and the Whatcom silt loam of northwestern Washington. Cherries are also produced in the Yakima Valley of Washington on what was broadly mapped as Yakima sandy loam in 1901. The Longrie, Posen, and associated soils should be mentioned for their production of cherries in Door County, Wisconsin, although they were not recognized as such on the older soil map of this important cherry-producing peninsula.

Small Fruits

Blackberry, raspberry, and dewberry. These crops may be grown on a variety of soils provided the soils are moderately fertile, well drained, easily cultivated, and of good moisture-holding capacity. Conditions of air drainage are important. Air pockets are subject to frost and disease, while exposure to strong winds causes unfavorable drying, both in winter and summer. These crops are generally grown on acid soils without the use of lime. Fertilization is practiced to only a limited degree. It is difficult to point out distinctive soils for the production of blackberries, raspberries, and dewberries, because of their wide distribution in small acreages. In many areas, these crops are grown on soils also selected for orchards, especially for peaches and cherries. Some of the representative soils on which they are grown are the Napanee silt loam of Michigan, the Baxter silt loam of the Ozarks of Missouri and Arkansas, and the Norfolk fine sandy loam of Texas. The Puyallup Valley of Washington probably represents the most intensive small-fruit district in the United States. The Everett-Alderwood-Kittsap association of soils occupies this area. Detailed surveys now in progress will furnish more specific information as to soil conditions in this and other small-fruit districts in the West.

Blueberry. Blueberry culture in recent years has rapidly reached importance in a few special areas of the Coastal Plain, as in New Jersey and North Carolina. As a part of the native vegetation, wild blueberries are associated with the leached and acid soils of the Podzols, Brown Podzolic, Gray-Brown Podzolic, and the Red and Yellow Podzolic groups, including both dry and imperfectly drained sandy soils.

It is recommended that land to be planted to blueberries in New Jersey consist of shallow muck overlying sand that is underlain with a claypan at 3 to 4 feet. Irrigation is necessary in dry weather if higher lying and less moist land is used. Deep peats are unsatisfactory. Methods of fertilization are being developed. The soil types best suited are Leon fine sand and Leon sand. These are associated members of the Lakewood-Dukes soil area shown on the soil map in the *Yearbook.*

Grape. The exact explanation of the apparent superiority of certain soils for the production of grapes of especially fine quality for fruit or wine has not yet been discovered. It may well be that local climatic factors associated with the occurrence of these soils are more important than the soil itself.

Most good grape soils are deep, mellow, well-drained sandy loam, loam, or silt loam soils, containing a considerable amount of gravel or shaly rock fragments. Favorable moisture retentiveness must go hand in hand with highly favorable soil aeration. A moderately high level of fertility must be maintained, especially with respect to phosphorus and potassium. While the soil may be moderately acid to slightly alkaline in reaction, the best soils for grapes are not seriously depleted in basic constituents.

The following soils are typical of the important grape districts: Dutchess gravelly silt loam of the Hudson Valley; Dunkirk gravelly loam of the Lake Erie Shore, in New York and Pennsylvania; Chenango loam, gravelly phase, of western New York; Baxter silt loam of the Ozarks; Aiken gravelly clay loam, Pleasanton gravelly sandy loam, Placentia sandy loam, and Hanford sandy loam of California.

Strawberry. Although light loams and sandy loams appear to be especially desirable, strawberries may be grown upon almost any type of soil, provided it is retentive of moisture, fairly fertile, and well drained. A moderate level of fertility is desirable. Fertilization is most intensively practiced in the Southeastern States. Phosphorus appears to be the element most needed in the soils of the Mississippi Valley region and nitrogen in the soils of the Coastal Plain. The reaction of the soil is not apparently a limiting factor in strawberry production, as the plant does reasonably well on soils very strongly acid as well as alkaline. Experiments have shown that best growth is obtained on soils with a range of pH 5.0 to 7.0 provided the organic content is relatively high, but with lower organic content the range for best growth is much less—5.7 to 6.5 or less.

The following soils are typical of areas well suited to the crop in commercial districts; Elkton sandy loam, artificially drained, of Delaware; Keyport sandy loam, artificially drained, of Virginia; Denham and Oliver silt loam of Louisiana; Baxter silt loam, Clarksville shale loam, and Hanceville shale loam of western Tennessee and the Ozarks area of Missouri and Arkansas.

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5

LAYING OUT AND PLANTING THE ORCHARD

Assuming that the location of the orchard has been determined, a plan or arrangement of the trees must be decided upon. Unless the land is so rugged and steep that the trees must follow the contour of the hillside, a geometric design is used to facilitate orchard operations.

Planting plans. The three most common arrangements of trees in an orchard are (1) the square, (2) the quincunx or diagonal, and (3) the hexagon or triangle. A fourth one which has had considerable emphasis recently is the contour system. (Figs. 36, 37.)

In the "square" system a tree is set in each corner of a square, whatever the distance may be. This is the usual plan in most sections and makes orchard operations easy to handle. If fillers are used one may be set between every two trees in the row and another row of fillers set between each two permanent rows so that when permanents are 40 x 40 feet the planting with fillers would be 20 x 20 feet. (Fig. 37.)

The quincunx system makes use of the square or rectangle, with a tree in the center. It is thus seen that the square system can be made into the quincunx plan by removing the filler from the middle of each side of the square and leaving the center one, or by planting in this fashion at the beginning. This method is particularly desirable when alternate rows are planted to different varieties. If a grower is undecided as to which variety he prefers, he may let the trees come into bearing and then retain either one without influencing the ultimate tree distribution. This plan is subject to the disadvantages which may result from carrying out cultural practices on the diagonal—a difficult procedure where the ground is not level. But more fruit can be produced over a longer period of time by this method than with the square system, since these semipermanents give a larger tree population per acre.

In the hexagonal system the trees are all equidistant, and as a result 15 per cent more trees per acre are planted than with the square system. It does not, however, lend itself well to the use of fillers.

A fourth method is known as the contour system.[1,4] The direct purpose involved is to so handle the land as to prevent or greatly reduce erosion, to make it more feasible to grow orchards and vineyards on hill lands, and in some instances to conserve moisture in the lands between the tree rows. By planting trees on high elevations to obtain frost-free sites and then cultivating the land, serious losses of soil have frequently occurred. (Fig. 38.)

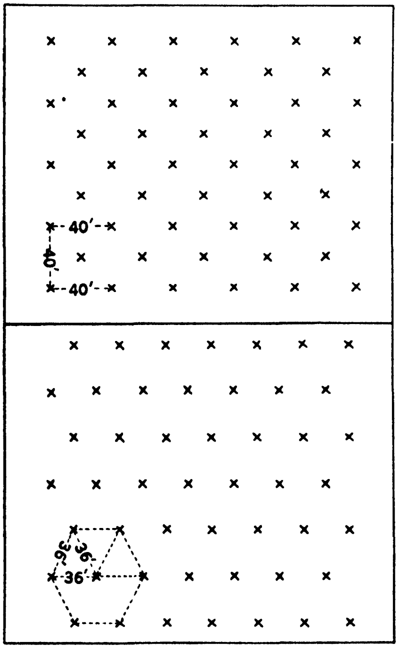


FIG. 36. Upper half, the diagonal or quincunx system; lower half, the hexagonal or triangle system.

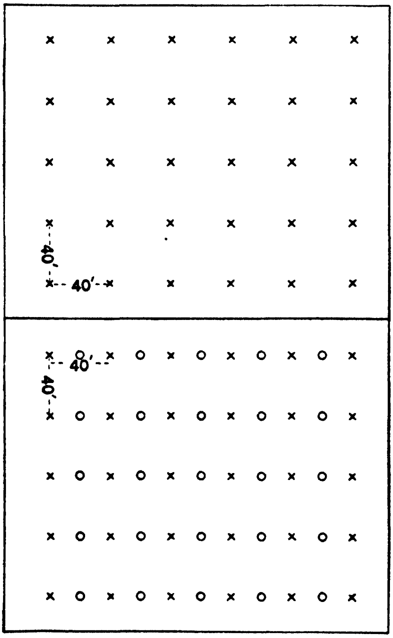
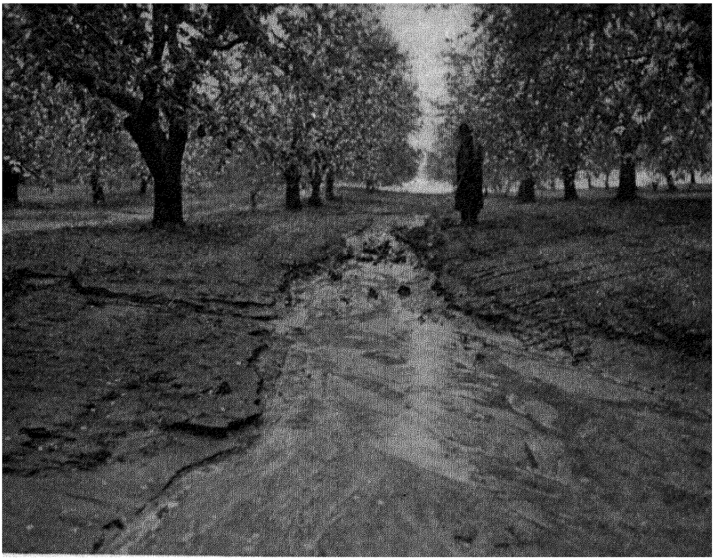


FIG. 37. Upper half, the square system of planting an orchard; lower half, the square system with fillers in one direction.

Contour planting and terracing of vineyards is an Old World practice, going back for several centuries to the Rhine River Valley, Germany, and elsewhere. The first commercial planting of this type in the U. S. was a citrus grove near Uplands, California, in 1895. The practice did not receive widespread recognition until about 1915. It is estimated at the time of writing that there are about 65,000 acres of contour plantings in the United States, but the acreage is increasing rather rapidly.

"Because of the variation in rainfall, slope, soil, and other conditions in the different sections of the country, a variety of both types and systems of orchard terraces are in use at the present time.

"First of all, terraces may be differentiated on the basis of grade, of which there are three general types: level, diversion grade, and irrigation grade. The first type is invariably in use where complete conservation of rainfall is desired. This may be the case in apple orchards where a permanent vegetative cover is maintained or in sections where semiarid conditions prevail. Level terraces are also adapted to short rows and in cases where a well-drained or porous soil, with or without auxiliary protection, decreases the likelihood of over-topping under heavy rain intensities.

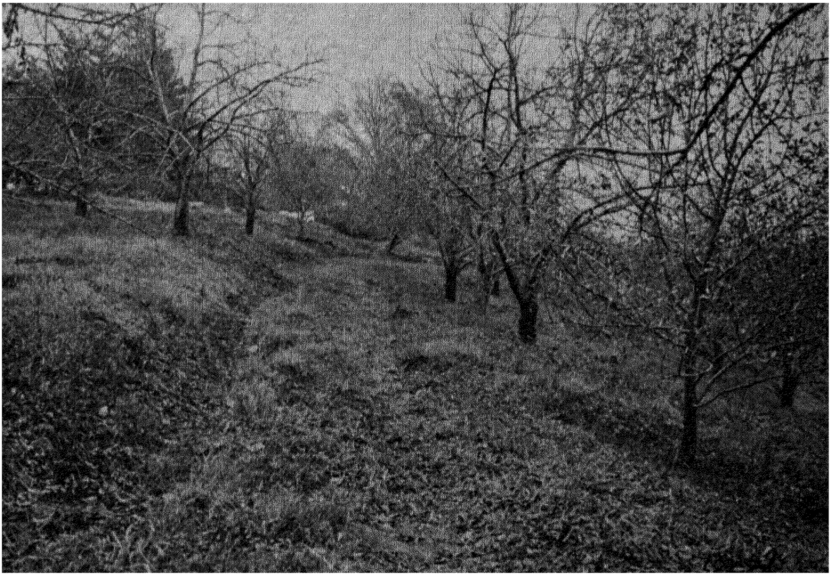


(Courtesy Soil Conservation Service, U. S. Dept. Agr.)

FIG. 38. Erosion in an orchard on a Coastal Plain soil, New Jersey.

"The diversion grade terrace is the type most commonly used in the humid sections, particularly for cultivated orchards where the tree rows are rather long. Diversion grade terraces may vary from practically level to 1.0 per cent in fall, depending upon interval, length, and soil factors. In the irrigation grade terrace, the use of which is almost entirely confined to California at the present time, the fall will run up to about 3 per cent. Such terraces also serve as diversion terraces during the rainy season, at which times the presence of orchard cover crops slows up the rate of flow and usually prevents damage by scouring.

"From the standpoint of shape or cross-section, orchard or vineyard terraces may be characterized as bench, narrow-base, or broad-base types. The bench terrace is the normal type where the slope is above approximately 15 per cent. On slopes less steep than that, terraces may be termed 'narrow-' or 'broad-base,' depending upon their width or cross-section. In general the narrow-base type (with a 4 to 6 foot ridge) is most common for orchard use." [1] (Figs. 39, 40, 41.)



(Courtesy Soil Conservation Service, U. S. Dept. Agr.)

FIG. 39. Apple orchard planted in 1908 on a 40 per cent slope, Havre de Grace, Maryland.

The selection of any of the plans will depend on the kind and variety of fruit, what fillers are to be used, the topography of the land, and the preference of the individual.

Distance of planting. This matter has never been definitely settled. There has been a fluctuation from close planting to wider spacing and back again to the use of as many trees as can be properly cared for. The distance of planting must be determined by the size the trees or plants are likely to attain at maturity. This in turn depends somewhat on the fertility and depth of soil, amount of rainfall or available moisture, variety, and whether or not fillers are to be used.

The following distances are frequently used:

	Feet		*In Row Feet*	*Between Rows Feet*
Apple	32 to 45	Blackberry	2½–3½	8 –10
Pear	25 to 35	Currant	4 –5	7 –9
Apricot	20	Gooseberry	4 –5	7 –9
Peach	20 to 24	Grape	8 –9	8 –10
Plum	20 to 24	Strawberry	1½–2	3½–4
Cherry, sour	24 to 30	Raspberry, red,	3 –4	7 –9
Cherry, sweet	25 to 30	black, purple	2½–4	7 –9
Quince	18 to 22	Dewberry	2½–5	2½–7
Dwarf trees	10 x 10	Blueberry	4	8
	10 x 15	Cranberry	½	1½
	15 x 15			

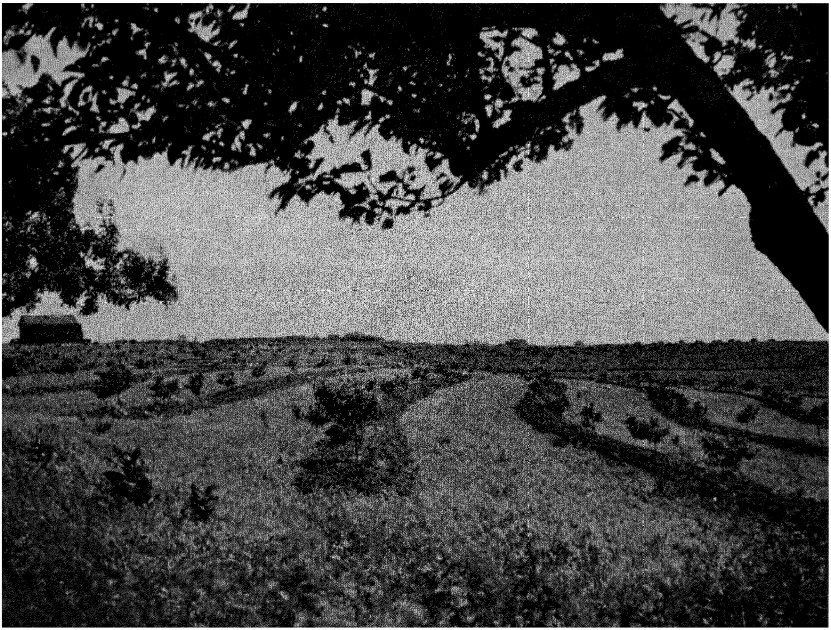
The number of plants required to plant an acre may be determined by multiplying the distance they stand apart and dividing the figure into the number of square feet in an acre (43,560). (Table 6.)

TABLE 6. NUMBER OF TREES OR PLANTS REQUIRED TO PLANT AN ACRE

Planting Distance Feet	*Square or Rectangular Method*	*Triangular Method*	*Planting Distance Feet*	*Square or Rectangular Method*	*Triangular Method*
1 x 4	10,890	—	20 x 20	109	125
1½ x 3½	8,300	—	22 x 22	90	104
3 x 8	1,815	—	25 x 25	70	80
3 x 9	1,613	—	30 x 30	48	56
4 x 8	1,361	—	35 x 35	35	40
4 x 10	1,089	—	40 x 40	27	31
8 x 10	544	—	45 x 45	22	29
10 x 10	436	502	50 x 50	17	20
15 x 15	194	223			

Laying out the orchard. After the planting plan has been selected and the ground prepared, it is necessary to locate the position to be occupied by each tree. For greater ease in orchard operations as well as for general appearance, it is desirable to have the trees well aligned in all directions. This can only be accomplished if considerable care is taken in the laying out of the orchard.

The first step is the selection of a base line, either a road, fence, or a temporary row of stakes in a straight line along one side of the field, allowing ample space between the boundaries of the field and the first tree rows. Along this line, stakes should be set at the correct distance for planting the first row of trees. By the use of a carpenter's square or surveyor's instrument, another base line is marked off in a similar manner along the edge of the field at right angles to the first. This row is then measured off at tree distances and stakes set. The square is then moved to the end of this row and the system repeated until stakes are set on all four sides of the orchard area. If the ground is very uneven it will also be necessary to set rows of stakes through the orchard in both directions at distances that can readily be seen. After this guide staking is done, three men set the stakes. The first sights in one direction, the second in the other direction, and the third man sets the stakes in position as signaled by the men doing the sighting. The guide stakes should be of light color and large enough to be seen easily. The remainder of the stakes need only be large enough to establish the position of the tree. If the ground is uneven, a few long poles with the bark peeled off the top end so as to show white will be very useful for sighting.

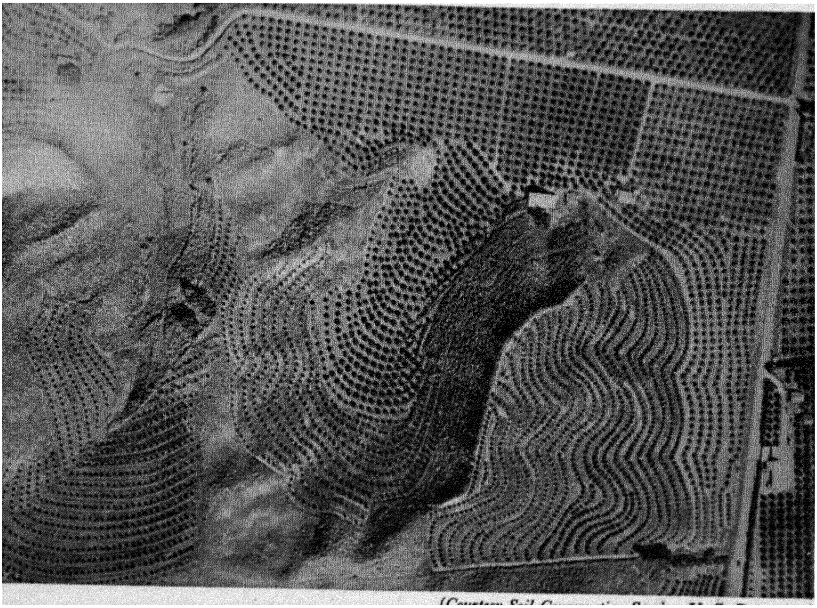


(Courtesy Soil Conservation Service, U. S. Dept. Agr.)

FIG. 40. Peach orchard planted on the contour, Benton Harbor, Michigan. Plowbuilt terraces with auxiliary cover crop planted in oats as nurse crop.

A method of locating trees in the square system is to fasten two boards together at an exact right angle, the boards to be just as long as the distance between trees is to be. A notch is cut in the end of each board and another in the right angle. By laying this piece of equipment against two stakes in the base line a third tree is located, and so on back and forth across the field.

In staking an orchard for setting by the triangular or hexagonal method a base line is established along one side as before mentioned. Then a large triangle with a ring in each corner is made of heavy wire or chain, the sides of which are the length of the planting distance desired. By placing two of the rings over stakes on the base line the third ring will exactly locate a tree in the second row. By using each new row as a base line the remainder of the stakes may be set in like manner until the whole area is laid out.



(*Courtesy Soil Conservation Service, U. S. Dept. Agr.*)

FIG. 41. Citrus orchard on irrigation grade, Santa Paula, California. Bench terraces.

Another method used when only two men are available for the work is to prepare a wire in length equal to the exact distance the trees are to be planted apart and with a loop in one end large enough to hold a small pointed stick. One man then places the end of the wire at a stake on the base line and the other with the stick through the loop strikes a small segment of a circle upon the ground where he thinks the stake should go. The wire is then held to the next stake in the row and second segment struck crossing the first. Where these two segments cross is the location of a tree in the second row. Likewise the succeeding trees and rows are established. Care must be taken if the field is of uneven topography to get the stakes the same distance apart on the level, otherwise, the rows will not be straight.

A common method of finding the right angle at the corners is the same as that used by a carpenter. He lays off one line 8 inches long, another at approximate right angles to it 6 inches long, and the hypotenuse must be 10 inches. Similarly, by use of 80 feet, 60 feet, and 100 feet the square corners can be determined and the sides of the orchard thus established.

The planting board. The digging of the hole for the tree necessitates the removal of the stake. To get the trunk of the tree in the exact location of the stake a planting board is used. This is a board about 4½ or 5 feet long (to be conveniently longer than the distance across the hole) and 6 inches wide. A V-shaped notch is cut in each end and a U-shaped notch is cut from one edge equidistant from the ends, and extending a little beyond the center of the board.

Before the stake is removed the board is placed with the center notch around the stake, then two small stakes are driven through the end notches. The board is removed until the hole is dug when it is returned to its original position, and the tree set in the notch previously occupied by the marker stake. This makes possible the exact alignment of the trees. However, it is always well to sight the trees as one goes along, to insure accuracy.

Digging the holes. Dr. John Warder once wrote that holes for fruit trees should be as big as the orchard, meaning that the land should be so well prepared that the roots could easily penetrate in all directions. Certainly the hole should be large enough to readily accommodate the roots without crowding. If there has been no previous preparation of the land the holes should be larger than otherwise in order to loosen the soil. Some orchardists do the excavating in the autumn, fill the holes with manure, remove this in the spring, plant the trees, and use the litter as a mulch about the trees. In no case should manure be put in among the tree roots.

Buying the trees. In buying nursery trees the safest rule is to purchase from a firm of known honesty and reputation. Competition has eliminated many of the irregular practices of former times. The substitution of varieties was one of the chief grievances, but this can be largely avoided today by the identification of trees in the nursery by means of leaf and other plant characters. '

There is some advantage in buying trees from a nearby point, as transportation charges are less and there is less likelihood of delay in transit with consequent drying out or freezing. However, these points should not outweigh the advantage of receiving good trees wherever they may be obtained. As far as the climate in which the trees were grown is concerned, little attention need be paid to it as long as they are well-grown, matured, and healthy. A northern grower can buy from the east, west, north, or south with impunity, and *vice versa.* One should look with suspicion on "bargains." Such trees may have been winter injured, early dug trees which are immature, heated trees, or trees with frosted roots, and it may not be easy to detect these injuries. Hence, avoid early dug stock, stock lacking in vigor, winter-injured trees, poorly handled ones, and stock with dead and discolored roots.

Grades of trees. In examining a nursery catalogue it will be noted that several grades of trees are listed. While the characterization of these grades varies somewhat with different nurserymen, the chief emphasis is usually placed on height and caliper of tree. The age of tree should always be stated also, as 1-year old and 2-year old. Three-year old trees are sometimes offered for sale, but usually they are not so easy to get established as younger ones.

Some varieties make a rather weak, crooked growth in the nursery but outgrow these troubles later. The nurseryman is not at fault in such cases, and the orchardist should inform himself regarding these points. The Rhode Island Greening, Canada Red, Williams Early, and Ensee seldom look well as nursery trees.

Planting the tree. In digging the hole the top soil should be kept separate from the subsoil and then thrown in around the roots when the tree is set. The soil should be well distributed around the roots, the tree worked up and down to insure that no large air spaces be left, and the soil packed closely by tamping. For best results the tree should be set about two inches deeper than it stood in the nursery, but too deep planting should be avoided. If the tree roots are kept puddled in water or thin mud, or at least kept from drying out, there will be less loss of trees. Where water can be added in addition it will do much to settle the soil.

The tree should be set so that the lowest lateral is toward the southwest and the tree slants slightly in the direction of prevailing winds, especially on exposed slopes.

Time of planting. Fruit trees may be planted in the spring or fall. In many places fall planting is to be recommended. The trees become established during the winter and make a better growth in the spring. However, if very cold weather occurs the young trees become "black hearted" and make a slow growth. The grower frequently has more time in the fall and more care can be taken in planting. The fact that the trees are not stored over winter in cellars is also of special benefit.

Peaches, apricots, and other tender fruits may suffer considerable winter injury in more severe climates, and hence must be spring-planted.[3] There is a considerable loss of both sweet and sour cherry trees the year of planting, and autumn planting may relieve a part of this where the climate permits.

Fall-planted trees are best left unpruned until spring, and if a mound of earth is thrown up about them it will give protection.

Spring-planted trees should be set as early as the ground will permit.

Handling trees before planting. It is very important that trees received for planting should not dry out at any time. If not planted as soon as received, they should be heeled in. It is important that the place selected should be in a protected spot and the soil well drained.

A trench is dug deep enough to accommodate all the roots. The bundles should be cut and varieties kept separated so that all the roots will be covered with soil. The trees should be placed close together in the row and slanted toward the south to prevent sun injury.

The boxes or bales should be opened when the trees are received, or heating may occur within the package and the trees injured.

Interplanting. An orchardist frequently desires a source of income while the trees are small and do not occupy the entire area. For this reason crops are frequently planted between the rows.

A common practice is to plant filler trees, usually a type which bears early and from which crops can be obtained for several seasons before they interfere with the permanent trees.

Where cultivation is practiced, crops such as potatoes, beans, or corn may be grown successfully for several seasons. Frequently small fruits are used for interplanting. These crops make the usual orchard practices difficult and require a more extensive soil fertility program. Hay crops are frequently cut where clean cultivation is not practiced.

When filler trees are used in an orchard they should be preferably of the same kind of fruit, since two different fruits seldom require the same cultural and spraying treatments. For this reason, the use of fillers of the same kind of fruit, but varieties which produce crops earlier than the permanents, is recommended. Soft fruits such as peaches and apricots have been very successful as fillers with apple trees in some instances, but most experienced orchardists have abandoned this idea and prefer to keep the fruits separate.

The feasibility of interplanted crops is determined by many factors. These include valuation of the land, fertility of the soil, taxes, and price per bushel. Where the investment is large and expenses high, interplanted crops or fillers should do much to carry expenses or produce a profit during the first few years.

The filler trees should be removed as soon as they materially interfere with the permanent trees; other crops as soon as they seriously limit necessary orchard practices.

Transplanting fruit trees. Fruit trees have infrequently been transplanted subsequent to their establishment in the orchard but the practice has never been widely approved. In fact, growers who have so utilized trees already planted have considered such transplanting an experiment. In the main, it would seem hardly advisable to transplant trees after they have become 3 or 4 years old since with increasing age of tree, a greater setback invariably results. In Vermont trees of bearing age showed much retardation in growth, and fruit production was deferred from 3 to 4 years.[2] Transplanting of large trees requires considerable labor and special equipment which may be quite expensive. While trees are usually transplanted with a large ball of earth, in another method the main roots are followed out to the end of the branches, all earth is removed and transplanting is quickly done without allowing the roots to dry. Trenches are necessary for each large root in the new location. This latter method has given better results and has required less cutting back than the "ball" method, especially if the tree is well braced and the ground well mulched. Following transplanting, applications of water may be required for a couple of years. It has also been suggested that the trunk and base of the main limbs should be wrapped until the roots have become established in the new location. The amount of pruning given the top will depend upon the amount of roots lost in transplanting. During severe winters considerable winter injury has followed heavy cutting back. It would thus seem, despite an occasional successful experience, that unless every condition such as variety, tree vigor, depth of soil, cheapness of labor, and market advantages are exceptionally favorable, transplanting of any but very young trees will hardly be a profitable operation.

Medium-age grapevines may be successfully transplanted, but the setback involves such a long time that it is usually preferable to set new plants. Early spring, before the frost leaves the ground is the best time for transplanting. The roots are severed at a distance of 2 to 3 feet from the trunk and to a depth of 1 foot or more. If the soil is frozen the vine with a ball of earth can be lifted and placed in the desired location. The soil should be mulched as with fruit trees. The vines should be pruned rather heavily, and no fruit should be allowed to develop during the first growing season.

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6

CULTURAL PRACTICES IN ORCHARDS

The conservation of the soil, as well as tree response to cultural systems, dictates to a considerable extent the method of handling the soil in an orchard or small-fruit plantation. Neither one should be considered apart from the other.

The kinds of fruits vary in their requirements as to culture, some being tolerant of widely different methods while others are more specific. In general it may be said that fruit trees respond directly to the soil type both in growth and yield. That is, the more favorable the soil, the less important is the exact cultural treatment to be followed. Young orchards in particular suffer readily from poor growing conditions, and hence delayed bearing of commercial crops is the result. Older trees, while more tolerant of neglect owing to the greater ramification of their root systems and also because of their greater reserve of food materials, will, nevertheless, usually respond readily to soil treatment. Moreover, it is not necessary and often not desirable to follow a single system throughout the life of an orchard. An orchard may be handled in one way while the trees are young and in some other manner when the trees are mature.

As in many other phases of production problems there is lack of agreement as to the best methods of orchard culture. Certainly there is no one best system for all orchards under all conditions. However, there are principles underlying the cultural problems which should guide the orchardist in deciding what system to use. Although not all the following objectives are essential for each orchard, the principal ones may be listed as follows:

1. To provide for a favorable moisture supply.
2. To supply sufficient nutrients for maximum production.
3. To add at least sufficient organic matter to offset any loss due to decomposition, erosion, or other factors.

4. To prevent or retard erosion.
5. To facilitate aeration and avoid serious compacting of the soil (i.e., to maintain a loose or friable condition).

While the use of manures and artificial fertilizers is intimately related to cultural problems, a full discussion of them must be considered later, except as general statements require mention.

The erosion factor. The loss of cultivated or bare soil by water or wind erosion can scarcely be overemphasized. Even on as little as a 3 per cent slope certain types of soil will erode badly. Loss of soil, nutrients, and organic matter by this method is responsible for the deterioration of many orchards and represents a permanent loss of the capital investment. Frequently erosion is not noted until gullies have appeared, but the insidious loss of most or all of the surface layer by sheet erosion or wind has had little attention in the past.

It has been customary to recommend sites of high elevation for orchards, sites which often afford the best possible conditions for the loss of soil when the orchard is cultivated. Some system to obviate this loss must be provided, and this fact influences the recommendations throughout this chapter.

Old sods or covers have frequently been plowed under in order to introduce a "soil building" program. Following quickly in the wake of this practice may come a destruction of the land which many years of good husbandry cannot replace. A compromise may be necessary between the maximum growth and production of the trees which comes with cultivation, and the conservation of the land.

The simplest method of avoiding erosion is to keep the land in a permanent cover, but some departure from this is frequently necessary for certain fruits and under special conditions.

Systems of culture. Broadly speaking, there are two general systems of orchard culture, one in which the land or a part of it is tilled and the other in which the land remains permanently in sod. There are a number of variations of these two systems, and no one can be arbitrarily established as superior to all others. Each one has its limitations as well as its advantages.

Terms defined. Sod culture describes any system of soil management wherein the trees are grown in sod without tillage of any kind, and without mulching the trees with litter. The grass may remain without cutting, but it is usually cut one or more times each season. It may be removed from the orchard or left to lie on the ground.

If the dry grass is insufficient at least partially to kill out the growth beneath the trees, it must still be termed sod culture. This system, like all the following may or may not involve the use of manure or artificial fertilizers or pasturing with stock. The *grass mulch* system consists in placing a mulch of litter (grass, straw, hay, corn stalks, or other material) beneath the trees, usually extending it a little beyond the drip of the branches. As the trees become large, material must be brought in from outside the orchard in order to mulch them properly. *Clean tillage* involves the plowing or disking of the land in the late fall or spring and tilling at intervals of about two weeks throughout the early summer, usually until about the first of July. After tillage is stopped, the ground lies bare until the following spring, hence no vegetation is turned into the soil. The *tillage* and *cover-crops* system is similar to the former, but in addition to the tillage a cover-crop is sown at the time of the last cultivation and the crop is plowed under in the late fall or spring. Instead of sowing a crop, the land may be allowed to grow up to weeds. *Intercropping*, which is often followed in young orchards, refers to the growing of any crop (usually a cultivated one) between the tree rows for the purpose of utilizing more fully the land not yet occupied by the trees. The system of *alternate-row* cultivation is in use in some regions and involves the tillage and perhaps cropping of every other "land" or area in the orchard. *Contour* or *strip* cultivation is similar in purpose to the above except that it is a device to give partial cultivation and yet have strips of grass land running along the contour of the orchard and thus prevent the erosive action of water running down the hillside without a break.

Essential Features of Cultural Systems

Sod culture. In the first half or perhaps three-quarters of the nineteenth century, the prevailing practice in this country was to grow fruit trees in sod land and along fence rows; especially was it true of the apple and pear. This was before the Western orchard sections had come into existence and before the rise of commercial orcharding in the East. In the last quarter of the past century, the cultivation of orchards was advocated by progressive growers, and the practice has continued in many sections until the present. There is now a definite trend back to some sort of a sod system, with fertilizers, especially for hilly or rolling topography.

The sod system without the use of nitrogen or partial cultivation is usually decidedly unfavorable, as shown by the growth of trees, color, size and amount of foliage, and yield of fruit. This is especially true of peaches and to a somewhat less extent with other stone fruits and grapes. This objection, particularly with apples and pears, may be partially or entirely overcome, however, by proper fertilization and mulching with litter, as discussed later.

On the other hand, certain advantages of growing trees in grass land may be cited as follows:

1. It prevents or retards the washing and erosion of the soil. This is less pertinent in northern sections where the ground is likely to be frozen during the "soft" weather of winter or early spring, such as occurs farther south. For instance, at Zanesville, Ohio, a record was kept of the rain-water penetration in soil under various types of cover.[21] The soil was very dry after months of drought and on August 2, 1934, there was a 2.45 inch rain. Within an hour and a half after the rain ceased, observations showed that on a bare washed soil on a 5 per cent slope there was a penetration of 1½ to 2 inches; in a timber lot with a good cover on a 12 per cent slope the penetration was to a depth of 8 inches; in a meadow with a 15 per cent slope it was 4 to 5 inches; on a very heavy blue grass sod (10 per cent slope), 7 inches; cultivated corn land, 2 inches between the rows and 5 inches close to corn plants.

2. The color of the fruit is usually higher, and therefore the fruit should have greater commercial value than when grown under cultivation. Not all varieties are affected alike, for some will develop a high color under tillage.

3. The land is in better condition for spring operations than when it has been plowed. This applies particularly to heavy soils which do not drain readily.

4. The dropped fruit is of higher market value.

5. Land that is too rocky to plow or to permit of tillage may be utilized by following some type of the sod system. There is a tendency to neglect sod orchards, and under most conditions it would be better to think of the practice as a *sod-nitrogen* system rather than sod alone. The latter actually constitutes a large part of the apple orchards of the Eastern United States.

Seeding for permanent sod. A great many grasses can be used successfully to secure a good permanent orchard sod. Orchard grass, timothy, bluegrass, red top, alfalfa, and the clovers may all be used for this purpose.

A mixture which has been used very successfully in orchards in developing a permanent sod is 4 pounds of alfalfa, 4 pounds of red clover, 2 pounds of alsike, and 4 pounds of timothy per acre. The addition of 3 or 4 pounds of bluegrass to the above combination is also recommended. This mixture should be sown by August 15 on a carefully prepared seedbed. Germination is better and more rapid if the seed is sown just following a shower.

In some places a higher rate of seeding is recommended as for instance, 6 to 8 pounds of timothy, 6 to 8 pounds of red clover, 2 pounds of alsike, and 4 pounds of blue grass.

Short-sod-rotation. The fact that orchards frequently decline when grown in sod where nitrogen fertilizers are used, has prompted some growers to plow the orchard occasionally and then seed it down again. This has come to be known as a *short-sod-rotation.* Either a nonlegume or legume sod may be used. It is recommended by the Pennsylvania Station as "an efficient means of building up a depleted orchard soil." After a sod of any kind becomes thick, the growth is checked and yields decline. Orchard sods should be turned under, or partially broken, frequently.[4] (Fig. 42.) The procedure is to break up the sod as soon as it becomes heavy, usually with a "weed hog" or spring tooth harrow rather than with a plow, followed by a year of cover crops seeded in late spring after as short a period of cultivation as is necessary to prepare a seedbed, and then back to sod again.

Sweet clover and alfalfa as well as other clover types will tolerate this treatment, although a light seeding (about 4 quarts of seed per acre) is usually needed after the harrowing.

Shaulis and Merkle [32] in continuing the Pennsylvania work give data that support the conclusion that "Sod management (either permanent or occasionally torn up) of orchards was found definitely superior as far as soil fertility is concerned to either clean-cultivation or the use of annual cover crops. The use of sods increased the total nitrogen content over that of forest soil." Not all would subscribe to this idea since many times it is almost impossible to obtain a stand of sod equal to the one destroyed.

Grass mulch. This method of handling an orchard is an attempt to emulate nature and allow litter to accumulate in increasing proportion beneath the trees and thus conserve moisture and add nutrients to the soil. It seems to have been put in practice simultaneously by F. P. Vergon of Delaware, Ohio, and Grant Hitchings of Syracuse, New York, during the latter part of the last century.

The term "mulch" as applied to the orchard has had too wide an interpretation, so that anything from mowing a sparse grass and allowing it to lie where it falls to spreading straw or other material to a depth of several inches or a foot beneath the trees has been designated as mulch.

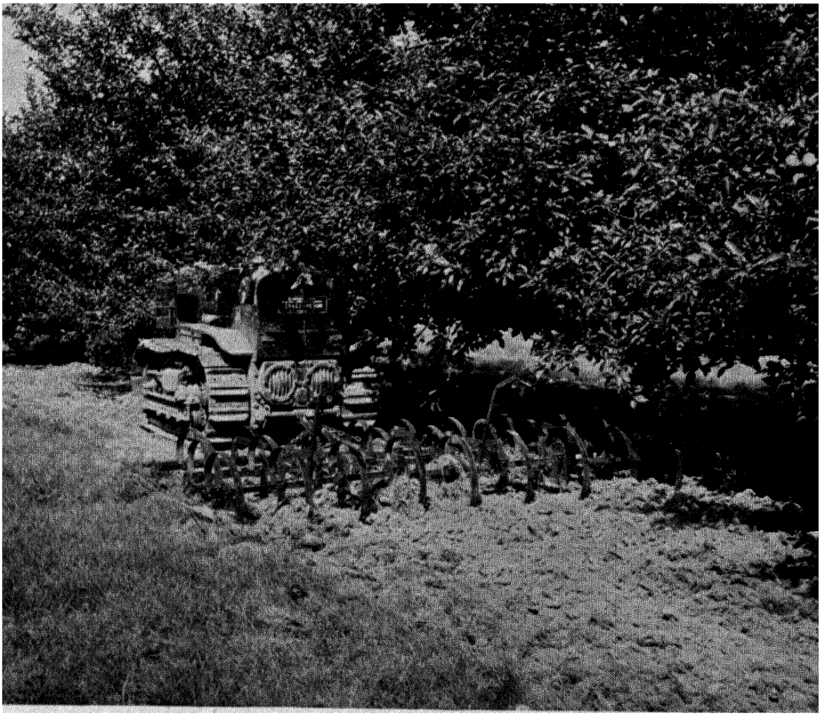

FIG. 42. "Weed hog" used to break up an old bluegrass sod in an orchard.

Certainly a true mulch system is as different from sod in its biological effect as sod is different from tillage. The fact that all the surface growth beneath the trees is destroyed or suppressed, together with other physical and biological results, places this system in a category by itself. (Fig. 43.)

This system of orchard culture was seriously criticized and questioned in the past, because it was generally believed that all plants would do better if cultivated, because of the scarcity and expense of mulch material, and also because of certain hazards, such as mice, insect pests, and danger from fire.

As compared with sod, a mulch of litter reduces the competition between the trees and ground cover for water and soil nutrients. It increases the penetrability of water and retards runoff. Evaporation of water from the soil is reduced to a minimum. The soil does not become compact, thus facilitating aeration of the soil. Additions of small amounts of potash and lime, as well as other inorganic nutrients to the soil, are made through decomposition of the litter.

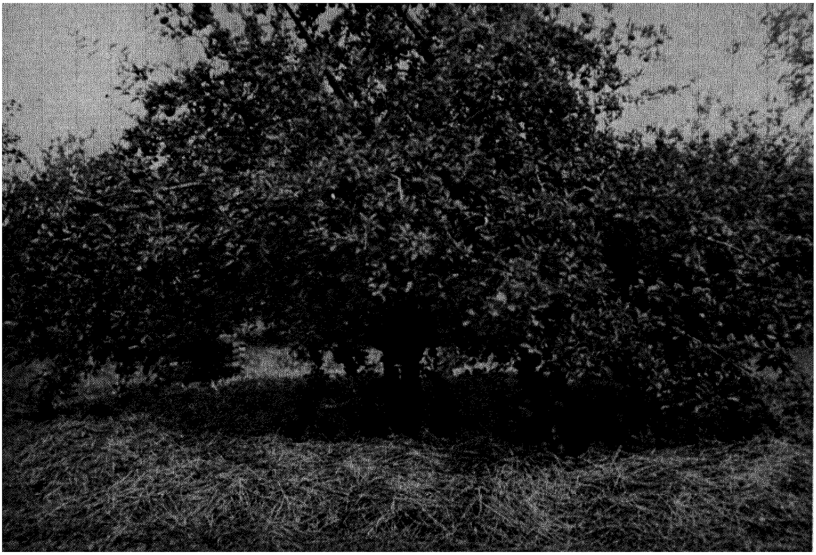

FIG. 43. A well-mulched tree.

Apart from these soil factors there are certain economic advantages and disadvantages of the mulch system that should be considered in placing an estimate upon this system as compared to cultivation for an orchard.

A mulched orchard can frequently be more economically sprayed than a cultivated one, particularly in the prebloom period when the soil is often very wet. It should be kept in mind that spraying, especially during the prebloom period, must be done on time. A delay of a day or two to allow a water-soaked soil to dry out may be sufficient time to permit an infection of apple scab. The necessity for spraying within definite time limits frequently results in serious packing of the soil from the weight of the heavy modern sprayer. The amount of damage caused in this way depends very largely on the type of soil. On loose, sandy soils which drain rapidly probably not much injury will result. On heavy, clay soils the physical condition of the soil may be affected for a season or more following the early spring spraying in a wet season.

Windfalls are cleaner from a sod than from a cultivated orchard. Mulch reduces to some extent the amount of bruising of the windfalls and fruit which falls during the picking operation.

Trees grown in sod, whether mulched or not, may be more subject to mice injury than those grown under cultivation. However, it should be stated that cultivation alone is no guarantee against mice injury, especially if a winter cover crop is grown or litter is allowed to accumulate at the base of the tree. A mulch undoubtedly increases this hazard considerably. In areas known to be infested with mice, it should be an annual practice to clean all litter away from the base of the trees by late October. This should be done regardless of whether the trees are cultivated, in sod, or mulched. Poison mice bait, and wire tree protectors should be used as a part of the regular orchard practice where rodents are especially numerous.* A cleared or bare area should be maintained immediately about the tree trunks as a fire break and to lessen injury from rodents. A cone of weathered cinders, gravel, or coal slack may be serviceable for the same purpose.

The possibility of fire is greater in a sod orchard than in one which is cultivated. This hazard is increased appreciably where a mulch is maintained. During dry periods the owner of a mulched orchard should be on guard against fire. An occasional cultivated area in a mulched orchard to serve as a fire-break helps to reduce the hazard. During prolonged dry periods care should be taken to have a supply of water quickly available and the orchard sprayer easily accessible to assist in extinguishing a fire.

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*Meadow mice are relatively abundant in rank grass and vegetative covers, which provide them with both food and shelter. Orchard cultural practices employing the use of green manure crops, heavy sods, and sods with additional mulch tend to encourage heavy populations of meadow mice. If mice are present, it is essential that orchardists conduct annual control operations to avoid loss of fruit trees. Tree-girdling mice are more easily and cheaply controlled under the mulch system than under any other type of orchard cover.

Recent studies by the Control Methods Research Laboratory of the U. S. Biological Survey have shown that greater attention must be given to the natural habits of mice if they are to be efficiently controlled. Meadow mice are road builders and do not leave their hidden trails to search for food. Poison baits (regardless of the rodenticide used) should be placed directly in these roadways and then covered. Meadow mice will not feed in the open.

The underground damage to the root system of fruit trees by pine mice during the winter months often escapes notice until too late to save the tree. Much of the activity of pine mice is below ground in a well-kept and extensive burrow system. Baits must reach the pine mouse where it lives and travels. Baits may be dropped into burrows opening to the surface, or the surface runways may be baited under cover.

Neither meadow mice nor pine mice are seed eaters. They prefer tender grass, clover, and the roots and tubers of many plants. Thus, apple, sweet potato, and carrot cut into small cubes make excellent bait, but when the ground is covered with windfall fruit, only grain will serve. Oats are the best of the grain baits.

Certain claims have been made for the mulch system which seem to be exaggerated or unwarranted. The trees do not come into commercial bearing much, if any, earlier. The color of the fruit is not necessarily any better, nor is there any great building up of organic matter in the soil as a result of this surface mulch except in the first inch or two, although it does retard its loss. It is not necessarily cheaper.

It is reported from New Zealand that excellent results have been secured by mulching citrus trees, as indicated by the dark green foliage and the smooth clear skin of the fruit.[3] Since mulching has been undertaken, the quantities of artificial manures necessary have been reduced by nearly half. The practice is to grow clovers or grasses in adjacent fields and place the cut materials in the late summer around the trees up to the limit of the branch spread. Mulching is practiced in a limited way in Florida and California also, but has not gained wide recognition.

Production of mulch material. One of the problems in a large mulch orchard is to secure sufficient litter. In some sections it is difficult to procure it at a price that would be considered economical. There are three common sources of such material. 1. It may be grown within the orchard; or 2. produced elsewhere for this purpose and hauled into the orchard; and 3. it may be purchased from an outside source. Some special types that have a limited use are seaweed, peat moss, peat, and sawdust.

One of the striking results secured by the Ohio Experiment Station in its early work was the effect of fertilizers on the increased growth of grass in the orchard, which provided a large supply of mulch material. The following figures show the results obtained in one orchard. (Table 7.)

It was found that when superphosphate was used, alone or in combination with potassium, a striking increase in growth of clovers resulted without any seeding. When nitrogen was used alone or in combination, the clovers were crowded out by timothy, bluegrass,

TABLE 7. EFFECTS OF FERTILIZERS ON YIELD OF MULCH WITHIN THE ORCHARD

(*AfterBallou*)[7]

Annual Fertilizer Treatment to an Acre	*Yield (lbs.)*	*Type of Growth Predominating*
Superphosphate 350 lbs.	2,716	Red clover
Superphosphate 350 lbs., muriate of potash, 175 lbs.	2,884	Red clover
Superphosphate 350 lbs.; muriate of potash, 175 lbs.; nitrate of soda, 350 lbs.	3,458	Timothy, red top, blue grass, orchard grass
Unfertilized	840	Poverty grass, weeds, briars

red top, and in some cases orchard grasses, which took possession of the land.[7, 8]

The above results are not obtained on all soils or under all climatic conditions. Neither phosphorus nor potassium may give measurable results on the ground cover with some soils but nitrogen usually results in a marked increase in the grass growth which can be used for mulch. The following results were obtained by the authors in one year on a rather infertile soil in central Ohio and are not exceptional. (Table 8.)

TABLE 8. YIELD OF GRASSES FROM NITROGEN FERTILIZATION IN AN ORCHARD—OHIO, 1937

Plot	*Treatment over Orchard*	*Yield of Dry Hay per Acre (lbs.)*	*Increase per Acre (lbs.)*
1	Untreated	1,573	....
2	200 lbs. Cyanamid	3,933	2,360
3	Same as Plot 2	4,689	3,116
4	Same as Plot 2	4,235	2,662
5	Same as Plot 2	4,311	2,738
6	400 lbs. Cyanamid	5,143	3,570

If part or all of the material is to be produced elsewhere than between the tree rows, it becomes an agronomic question as to what can be grown best and cheapest. It may require an acre of land or more to produce enough mulch for an acre of mature trees. Such crops as Siberian or German millet sown about June 1 and cut September 1, followed by rye and cut in the spring, should give about 4 to 5 tons of fresh material per acre on fertile land that is fertilized. Sudan grass and soybeans make a satisfactory combination in some regions and may yield 2½ tons per acre. Timothy top-dressed with about 300 pounds of sulphate of ammonia or Cyanamid may yield 1½ to 2 tons per acre. Other crops or combinations may be used as dictated by local conditions.

Amount and cost of mulch. Various estimates are given of the amount of straw or other material that is required for mulching. The size of the tree is the principal factor. Two to 3 hundred pounds (2 to 3 bales) of straw are usually necessary for the initial mulching of a mature tree. After that one hundred pounds per year may be sufficient. While price varies, an estimated value of 6 dollars per ton, may be given, which would be from 9 to 12 dollars per acre per year, if there were 30 trees per acre. Frequently straw can be obtained for less than half that amount, but the grower can easily calculate the cost of mulching when he knows the price of the material he purchases.

Clean cultivation has never been widely used in the eastern United States, but in sections of the Northwest and in California it was the prevailing system for a number of years. It is still commonly practiced in parts of England. The danger of clean cultivation (without a cover crop) seems to be in its ultimate effect on the soil itself. Especially is this true in sections in which there is a long growing season and the summer heat is intense. While this system may and often does give satisfactory results for a period of years, it is likely to end in a premature decline of the trees and a decrease in size of the fruit. Aside from erosion, the depletion of organic matter and ultimate compacting of the soil are conspicuous. It must be remembered that cultivation stimulates bacterial action, and nitrate nitrogen is produced from proteins and other insoluble nitrogen compounds of the organic matter. As these nitrates are soluble they leach downward, and large amounts of nitrogen are lost.

The idea of a finely divided soil was early advocated by Tull [38] on a false premise, but the teaching once established lasted a long time. His theory was that the minute particles entered the roots and were translocated through the plant.

Tillage and cover-crop system. The value of turning a growing crop into the soil instead of harvesting it has long been recognized by agriculturists. Pieters [30] points out that green manuring not only played a part in the farming of the Greeks and Romans as indicated in the writings of Theophrastus who died in 287 B.C. and Varro (116–27 B.C.), but also of the early Chinese. "The fertilizing value of grass or weeds had begun to be realized as early as the time of the Chou dynasty, (1134–247 B.C.)." Legumes were especially valued by the Greeks and Romans as indicated by the following advice, "lupines, field beans, and vetch manure corn land." [40]

Since farm lands are known to benefit by such husbandry, the orchardist established the practice of growing some crop for a part of the season and plowing it into the soil. This system of tillage and cover crops has been considered superior to all others in many sections and the results in some sections would seem to justify this opinion. Trees usually thrive well under tillage with cover crops, and their appearance and production is conspicuous as compared with trees in sod land. Crops that are unsuited to the purpose, erosion, ultimate compacting of soils, and depletion of organic matter have mitigated against it in some regions.

It remains as pertinent as ever that tillage and green cropping go together. But meager crops are inadequate to maintain the original organic matter content. This means that all-over fertilization or manuring of the soil is desirable unless the soil is fertile. The system is designed to maintain a favorable medium for the more desirable soil flora; it increases nitrification; makes more available the nutrients of the soil; and retards erosion at times when the cover crops are on the land.

Despite the value assigned to cover crops in orchards, Fagan, *et al.* report as follows after 25 years of experimenting: "Trees receiving annual tillage with July seeding of cover crops have not done so well as those under sod rotations. If the cover crops are seeded in early June, as has been practiced since 1929, the difference may not be so marked." [19] They further have pointed out that the amount of cover crop produced is an excellent index of the general fertility of the land and that the productiveness of an orchard can be predicted a decade in advance by the type of crop which is grown between the trees.

Relative value of soil management methods. It can thus be seen that there is a complex of factors to be considered in selecting a soil management system. The three most commonly followed are, 1. sod (nonlegume, legume, or mixed), 2. mulch, and 3. tillage (with or without cover crops or intercrops). The maintenance or conservation of the soil itself and the response or behavior of the trees are the two important criteria to be considered.

The sod system, usually with the use of a nitrogen or a complete fertilizer beneath the trees or over the entire orchard area, is widely followed throughout the eastern United States for apple and pear orchards. A legume sod or cover is more common in the West. The fact that it is reasonably successful and conserves the land is the best answer to its further use. From the standpoint of the conservation of moisture, organic matter, soil porosity, and a supply of nutrients from the decaying plant material, it is not equal to the mulch system. Its complete adequacy, however, depends upon the nature of the land on which the orchard is grown. The sod system is less well adapted to stone fruits and is not satisfactory for small fruits.

When tillage is used it should usually be accompanied by the use of cover crops. The cooler and more moist the climate the less serious does the absence of the latter become. Tillage usually stimulates growth, stimulates nitrification of the soil if the soil is supplied with organic matter, and is a fair conserver of moisture. It may, and often does, destroy the physical condition of the soil, resulting in compacting and a gradual loss of organic matter unless adequate cover crops or manure are plowed into the land. The system is particularly effective with peaches, apricots, grapes, cherries, citrus, and plums. Fertilization of the cultivated land may or may not be necessary with apples, but is usually necessary with peaches and apricots.

This situation leaves a choice of methods depending upon the fruit and the soil.

The mulch system is gaining rather than losing in popularity. On rolling or hilly land, or under any circumstances where moisture is limiting, it is to be recommended provided the hazards of fire and mice can be controlled. There are less rapid fluctuations in all particulars under mulch than any other system and it has less objections, in the main, than has any other. It is particularly adapted to the apple, pear, quince, and small fruits, but is less well adapted to cherries and plums, and it is yet to be proven whether it will have a wide place with the peach.

Cover crops. This term was first used in this connection by Professor L. H. Bailey in 1893 in Bulletin 61 of the New York (Cornell) Experiment Station. It has its origin from the fact that such crops are planted in mid- or late summer and are designed to fulfill several functions. They make a cover over the land and act as a winter protection. They recover from the soil surplus moisture together with various nutrients. They produce on the land itself a green-manure crop. And perhaps most important of all, they prevent erosion.

In considering the role of cover crops in the soil it should be remembered that legumes contain a greater amount of nitrogen in relation to the amount of carbon in their composition than nonlegumes. This is spoken of as the carbon-nitrogen ratio. Nonlegumes have a wide C/N ratio and legumes a narrow one. In order to minimize the depressing effect upon nitrogen of incorporating a mature nonlegume crop with the soil, extra nitrogen fertilizer should be used. This usually can be done cheaply and still retain the ligneous portion of the organic matter. An ideal type of decomposition is obtained by planting a legume and a nonlegume together, as soybeans and sudan grass or rye and vetch.

The best crops to use for this purpose will depend upon the soil, site, and geographical location. They may be conveniently divided into summer and winter cover crops as follows.

Summer Cover Crops

Soybeans (Soja max). Soybeans are an ideal summer cover crop for improving the physical condition of the soil. They are better adapted to orchards under 15 years of age than to older ones. Soybeans are generally disked under late in the summer and followed by a winter cover crop. While soybeans are more tolerant of acid soils than red clover, they will not do well on strongly acid soils nor those deficient in organic matter. The rate of seeding recommended is 1½ to 2 bushels per acre. Soybeans should be seeded on a good seedbed June 1 to 15. The drill should not be set too deep.

This crop requires special inoculation inasmuch as the bacteria which work on it are not the same as for other legumes. The inoculant can either be purchased or soil from a field on which they had previously been grown can be used for the purpose.

Cowpeas (Vigna sinensis). Cowpeas are another summer cover crop occasionally used in orchards. This crop is handled in much the same way as soybeans but the latter crop is to be preferred, except on very poor soils.

Millet (Setara italica, Panicum miliaceum, Echinochloa frumentacea, *et al.*). Millet is sometimes used as a summer cover crop and will usually make good growth in an orchard. In dry years the competition with the trees for water makes its use a questionable practice. It is seeded at the rate of 40 to 50 pounds per acre. When combined with soybeans, the rate of seeding is 1 bushel of soybeans and 15 pounds of millet.

Sudan grass (Sorghum vulgare sudanensis). Sudan grass is another of the grasses sometimes used for an orchard cover crop. Like millet, it is objectionable in dry years. It is a good crop to use where mere tonnage of organic matter is a factor and is especially valuable where soil aeration is inadequate. However, a rather heavy application of nitrogen fertilizer should accompany the use of either millet or Sudan grass. Sudan grass is seeded at the rate of 25 to 30 pounds per acre. This crop makes a very rapid growth and may sometimes be used where soybeans have failed to grow. (Fig. 44.)

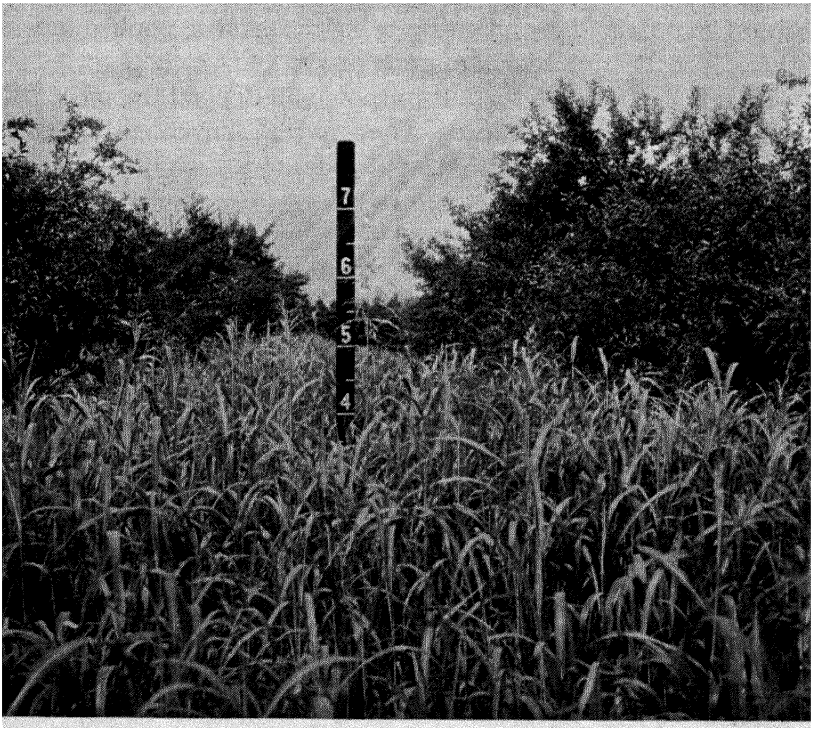

FIG. 44. Sudan grass used as a cover crop in an apple orchard.

Buckwheat (Fagopyrum esculentum). The chief use for buckwheat as an orchard cover crop is in young orchards not yet in bearing. It is particularly adapted to the Northern Appalachian area and to portions of the Lake States. This crop thrives where the climate is moist and cool but is very sensitive to frost. It does well on rather infertile sandy loams and may be seeded in the summer as late as the last of July and still mature a seed crop. If left standing, it will provide sufficient ground cover over winter to prevent erosion except in hilly orchards.

The following spring the orchard can be cultivated for a few weeks, and after cultivation has ceased there will be sufficient volunteer buckwheat to provide a good cover crop for the late summer. This procedure may be repeated for another year, thus providing a cover crop for 3 successive years from one seeding. Buckwheat is also a valuable source of honey during the fall months, which makes it have an added value as an orchard cover crop. The rate of seeding for a cover crop is 6 pecks per acre.

Lespedeza (L. striata). Korean lespedeza in an orchard serves as a permanent crop. It is, however, an annual plant and should be seeded rather early in the spring to allow the plants to develop seed before freezing weather the following autumn. In the north the plant does not attain enough height to make it an ideal cover for an orchard. The rate of seeding is 20–25 pounds per acre.

Weeds frequently grow much taller than lespedeza and necessitate a special mowing in midsummer. Owing to the thick stand this plant must be rated as a good ground cover rather than a rank-growing cover crop. In the south lespedeza, no doubt, has a place as an orchard cover crop.

Crotalaria (C. spectabilis and C. striata). This cover crop has come into prominence particularly in Florida and southern areas for citrus and tung-oil groves, although it is also used in pecan plantings. It is annual in most regions and attains a height of from 3 to 6 feet. It is particularly adapted for sandy lands and is sown at the rate of 15 to 30 pounds per acre.

Sesbania (S. macrocarpa). This is a North American plant which has been used as a green-manure crop in the southern states. This annual legume attains a height of 6 to 8 feet. It is seeded at the rate of 20 pounds per acre. It has succeeded well on muck land as far north as northern Ohio.

Under Texas conditions, cover crops are recommended with citrus plantings, since clean tillage hastens oxidation of organic matter and may result in excessive vegetative development during the first few years of the life of the trees. Cowpeas and sesbania are the most popular summer legumes and annual yellow sweet clover (*Melilotus indica*) and hairy vetch winter ones. Pigeon peas, Senna, and *Crotalaria incana* are also used as summer cover crops, while

Hubam clover, Tangier peas, and Hairy Peruvian alfalfa are rated as promising.

Winter Cover Crops

Rye or wheat. Rye and wheat serve about the same purpose as cover crops in an orchard. The price of seed is a determining factor in the choice between the two. Rye makes a faster growth in the spring, and this is at once its greatest advantage and disadvantage as compared with wheat. If plowed under at the proper time in the spring, rye is quite satisfactory; on the other hand, if the plowing is delayed a little too long, frequently a matter of only a few days, rye may be injurious to the trees because of the amount of moisture taken from the soil. Rye is an ideal winter cover, especially where erosion is a problem. Wheat makes nearly as good a ground cover for the winter and develops more slowly in the spring. Eight to 10 pecks of either rye or wheat are about the rate of seeding for an orchard cover crop.

Rye and vetch. Rye has frequently been used in combination with vetch as a cover crop in orchards, and, when a good stand of vetch is secured, this combination generally produces a heavy tonnage of green material. Some growers have followed the practice of saving sufficient acreage of the combined rye and vetch to thresh for seed in periods when the price of vetch seed is high. The main difficulty encountered in this practice is that the mass of rye and vetch is apt to lodge before maturity and make harvesting difficult or impossible. The rate of seeding for this combination is 5 to 6 pecks of rye and 15 to 20 pounds of vetch per acre.

Rye is not exacting in its soil requirements, doing well on soils of relatively low fertility as well as those well supplied with nitrogen and mineral nutrients. It is likewise tolerant of a wide range of soil reaction.

Hairy vetch (Vicia villosa). Vetch may be rated as one of the best winter cover crops for an orchard when a good stand is secured; however, inoculation is necessary to secure a good stand. Given a good stand the quality of organic matter resulting is not only above the average for winter cover crops but is very high in nitrogen, containing from 3 to 4 per cent of nitrogen up to June 10. It may be seeded any time after August 15. Because of a rather slow development in the spring, vetch should not be plowed under until the latter part of May. Like buckwheat, vetch may be allowed to ripen and reseed itself. The seedbed for hairy vetch should be well fitted. Twenty-five to 30 pounds of seed per acre are required when vetch is seeded alone.

Oats (Avena sp.) Oats are, of course, not an overwintering crop except in the South. However, they are useful as a fall cover crop, and, if seeded by mid-August, will usually make enough growth to provide protection for the ground over winter. They are best adapted to a cool moist climate and a soil that is not alkaline in nature. Eight to 12 pecks of seed per acre are required.

Crimson clover (Trifolium incarnatum). Crimson clover has been none too successful as an orchard cover crop. It usually dies out badly during severe winters. When it does succeed it develops into a very good cover crop. It has a tendency to grow in a matted condition but not as rank as vetch. This crop may also be combined with rye or wheat. Fifteen pounds per acre constitute the recommended rate of seeding. It should be seeded during July for winter hardiness.

Sweet clover (Melilotus alba and M. officinalis). The chief value of sweet clover as an orchard cover crop is in the early life of the orchard and, where large quantities of humus are desirable, in bearing orchards. Sweet clover should be sown early in the spring and plowed under the following spring, about May. Agronomists get an excellent stand by sowing unscarified seed on wheat at the rate of 15 pounds per acre from January to the middle of March and shortly after the latter date 5 to 6 pounds of scarified seed to the acre. For best results, it should not be cut in the seeding year. If left much later than May it is very apt to compete seriously with the trees for moisture. Fifteen to 20 pounds of seed per acre are recommended. Morris and Overley report that the biennial sweet clover and Hubam clover have been used with marked success in Washington. Their use results in rapid improvement of the soil in both physical condition and fertility. Both crops grow tall, however, and make summer spraying and harvesting difficult, and for that reason are often rejected.[28]

Davidson [18] states that a good crop of sweet clover about 13 inches high when plowed under, would soon add to the soil about as much available nitrogen as an application of 12 tons of stable manure or 200 pounds of nitrate of soda per acre. A practice recommended by the New Jersey Station is to plow under the sweet clover in alternate middles between rows of trees during early May and leave the remainder to reseed itself.

Alfalfa (Medicago sativa). Alfalfa is not widely used strictly as a cover crop. It is possible to use it much in the same manner as suggested for sweet clover and it would be preferable in every way except for seed cost. Generally the price of the seed has discouraged its use as an annual cover crop. It is more valuable either alone or as part of a mixture of other clovers and grasses for a permanent sod. Where alfalfa is used as a permanent cover crop a grower should be prepared to irrigate. Alfalfa may be seeded either early in the spring or early in August. In Washington the entire annual top growth of the plant is commonly worked into the soil each year. Hairy Peruvian alfalfa makes a good annual cover. It is seeded at the rate of 12 to 15 pounds per acre.

Clovers. Red clover and alsike are both valuable crops to precede the planting of an orchard or to grow in the orchard during the early years. In bearing orchards these crops are useful mainly when grown in combination with other clovers and grasses and where the orchards are mown and the clippings used for mulch.

Treatment of soil in preparation for seeding cover crops. A good seedbed is one of the main essentials in securing a good stand of any cover crop. A complete fertilizer at the rate commonly used in seeding wheat helps to secure a good stand (250 to 300 pounds of a 2-12-6).,

A detailed discussion of the adaptability of the cover crops in the foregoing list to different soil types is not possible here. It is of course assumed that the orchardist will not attempt to grow those crops which require soil having a near neutral reaction (such as alfalfa and sweet clover) on acid soils without first applying the required lime to supply the necessary calcium.

Many of the cover crops in the foregoing list require inoculation whether grown for orchard crops or for mulching purposes.

Effect of cultural system on the soil. Before examining the effects of these cultural systems on the trees, it would be well to follow the investigations as they affect the soil itself. While the student must consult works on soil science for a fuller treatment of this subject, some reference to it is necessary in order to secure a basis for the cultural methods used in orchards.

It is axiomatic that an abundance of available inorganic nutrient materials and moisture will give a better development of trees and production of fruit than when these are deficient at the critical period of development. It is equally detrimental to have excesses of moisture and in some cases nitrates or certain other materials, and this should be avoided.

Organic matter. The presence or additions of organic matter in agricultural and orchard soils has long been stressed. The role ascribed to it is its effect on water holding, porosity, aeration, and other physical properties, its influence on phosphorus availability, base holding power, aluminum solubility, and its important relation to nitrogen content.

Organic matter consists of various complex carbon compounds, or it may be thought of as plant and animal remains, mostly the former. Animal manures and green manures, mostly the latter, have been the principal sources of organic matter incorporated with orchard soils. The decaying roots or stubble of the orchard cover are also important additions to the organic supply.

Waksman [41] defines "humus" as "that part of the soil organic matter which gives to it its dark color and which is more or less resistant to decomposition. It is the result of the accumulation of substances of plant origin—on the one hand, largely lignins, and to some extent the fats and waxes and perhaps certain nitrogenous substances, and on the other, substances synthesized by microörganisms, nitrogenous in nature." In other words, when organic matter is added to the soil, the various sugars, starches, hemicelluloses, celluloses, and proteins are rapidly decomposed and the lignins remain for a much longer time. One may easily hold the erroneous concept that the vegetable material which is turned into the soil will accumulate as a "bank account" which can be drawn upon years afterward by mature trees. The supply must be maintained annually if the soil is cultivated and for that reason a complete fertilizer should be applied over the entire orchard area in order to produce large yields rather than meagre ones of cover crops or grass.

Certainly the student should recognize, (1) the more or less coarse "organic materials" which are turned into the soil and (2) the "organic matter" which may be soluble or in the colloidal state. Both are usually determined together, but the orchardist has direct concern with the plant refuse which affects porosity, tilth, looseness of the soil, and related properties.

In this connection we are particularly interested in the role of organic matter in the soil and the means within the hands of the orchardist to conserve or build up the supply. These matters are directly related to the cultural system used and it is necessary to compare one with the other in discussing the problem.

In order to make definite determinations of the organic matter present in a given soil type as a result of the cultural system used, a block of trees on a Wooster silt loam soil was taken for study.[24] The treatments of sod, tillage with cover crops, and mulch had been in effect for a comparatively long time. One orchard had been in mulch for 37 years (Orchard A) and the other (Orchard C) had a portion in tillage and another part in mulch for 22 years, at the time the study was made. Under the conditions of these studies, the organic matter content was about the same under the mulch and sod, but it was much lower in the cultivated area, even though a system of cover crops had been used. (Table 9 and Fig. 45.)

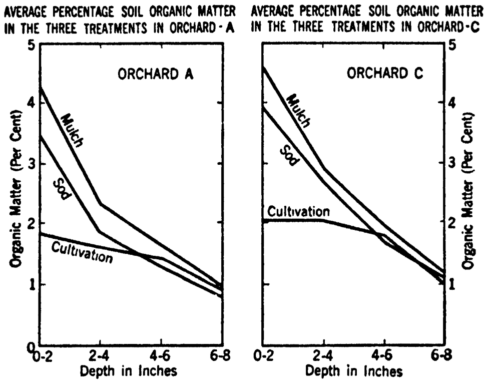

FIG. 45. Average soil organic matter content (C x 1.724) at various depths under sod, mulch, and cultivation. See text for discussion of significance of results.

It should not be inferred that the organic matter under sod and mulch had accumulated as a result of the mulch, so much as that the tillage and cover crop system had resulted in a loss of the original organic matter of the soil. These data present a challenge to those who advocate frequent tillage under like climatic conditions.

Investigations at the California Experiment Station show a surprising negative effect on the water-holding capacity of soils even from large quantities of organic matter. "It now appears that the addition of organic matter to the soil by the application of manure or green cover crops does not have as much effect on the physical characteristics of the soil as has been generally assumed. Investigations show that the increases in water-holding capacity of the soil are very slight, even when barnyard manure is applied in amounts greatly in excess of what would be practicable in commercial farming. Studies show that the application of large amounts of organic matter results in very slight changes in the water-holding capacity, the rate and height of the rise of water in the soil, the volume weight, and the consistence of the soil. As far as these properties determine the physical condition of the soil, it is shown that the soil is very slightly affected." [14]

At the Pennsylvania Agricultural Experiment Station a set of field plots has been under differential treatment since 1881. Here the grass division strips which separate the plots have been in permanent grass since 1867. In 1922 (55 years) a study was

TABLE 9. SOIL ORGANIC MATTER DETERMINATIONS IN ORCHARDS IN SOD, MULCH, AND CULTIVATION

(*After Havis and Gourley*)[24]

No. of Tree Near Which Sample Was Taken	*Mulch*				*Sod*				*Cultivation*			
	Depth (Inches) of Layer Sampled				*Depth (Inches) of Layer Sampled*				*Depth (Inches) of Layer Sampled*			
	0–2	*2–4*	*4–6*	*6–8*	*0–2*	*2–4*	*4–6*	*6–8*	*0–2*	*2–4*	*4–6*	*6–8*
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Orchard A												
197	3.73	2.17	1.66	0.82	3.29	1.78	1.48	0.80				
327	5.89	3.33	1.65	0.93	4.52	2.12	1.55	1.04				
329	3.66	1.82	1.46	1.03	2.69	1.60	1.19	0.72				
289	3.91	2.04	1.65	1.14	3.60	2.08	1.01	0.77				
301[a]									1.87	1.64	1.45	0.94
Orchard C												
4/2	4.41	2.92	2.42	1.42	2.91	2.21	1.92	1.40				
4/5	4.80	3.40	2.01	1.35	4.52	3.30	1.91	1.31				
3/2	4.36	3.20	2.10	1.22	3.86	3.14	2.10	1.30				
3/5	5.06	2.17	1.55	1.02	4.60	2.33	1.04	0.85				
2/1									2.07	1.71	1.25	0.84
1/5									1.64	1.74	1.73	0.78
2/1									1.91	2.30	1.94	1.00
2/4									2.12	2.14	2.01	1.26

[a] Previously in sod, cultivated since spring of 1927.

made of the organic matter and nitrogen content of the sod soils and also the cultivated plot areas. On an average the untreated grass strip soils contained 79,327 pounds per acre of organic matter and 3,754 pounds of nitrogen compared to 63,028 pounds of organic matter and 2,936 pounds of nitrogen in the fertilized plot soils. The plot soil which has received a total of 123 tons of manure in addition to the crop residues (roots and stubble) contained 78,480 pounds per acre of organic matter in comparison with the adjacent grass strip which contained 90,745 pounds.

In some grape fertilizer experiments at Vineland, Ontario, similar results to the above were secured after eight years of work. The difference between untreated and green manure plots or plots which received two tons of straw per acre for five consecutive years was very slight.[39]

The conclusion from these and other similar studies is that tillage, while beneficial to trees, is likely to deplete the organic matter and points to the importance of growing large crops of green manures or else substituting some sort of a sod or mulch system for tillage. Bradfield has stated that "we should look upon tillage operations as we do on surgical operations, indispensable at times, but to be avoided whenever possible." [12]

Effect on temperature. The temperature of the surface soil is profoundly influenced by the cultural treatment used. Bare, exposed soil or that where a cover crop is grown responds more quickly and to a greater extent to the air temperature than ground which is well covered (insulated) by a mulch or a sod. Bouyoucos [11] showed that a soil that is tilled and bare may be as much as five degrees hotter during midsummer than one that is in sod.

Records throughout the year in the orchards of the Ohio Station illustrate the fluctuation of cultivated land with air temperature as contrasted with the more conservative mulch system. (Fig. 46.) The smoothed curve which is inserted in this figure shows graphically that the mulched area is lowest in temperature during the summer and highest in winter with the tilled area at the other extreme and sod land intermediate.

Clark of the New Jersey Station reported that the temperature of the soil in a raspberry planting at a depth of three inches below the surface was as much as 20 degrees higher where the soil was not mulched than where the mulch was present. The readings were made during the hottest part of the day.[15]

Effect on nitrates. Since nitrogen and moisture are more likely to be limiting in American orchards than any other factors they require special consideration. Nitrogen may be purchased in the form of a fertilizer but it also occurs naturally in the soil under favorable conditions. Therefore any cultural system that supplies a source of nitrogen (e.g., organic matter) and also favors nitrification without excessive oxidation of the organic matter is to be sought.

In several investigations in both young and mature orchards, it has been found that the amount of nitrates under sod is likely to be very low, in fact so low as to be the limiting factor in production. However, Lyon and Bizzell [25] have shown that nitrification is not depressed when leguminous crops are grown, in contrast to the conditions under rye and the grasses. When the soil on which grass has been growing is stirred by cultivation, the nitrates are greatly increased, especially when a leguminous crop is plowed into the soil annually. In cases in which the moisture is conserved also, the results of cultivation on the orchards are likely to be very beneficial; in fact, this practice is usually one of the first steps in orchard renovation.

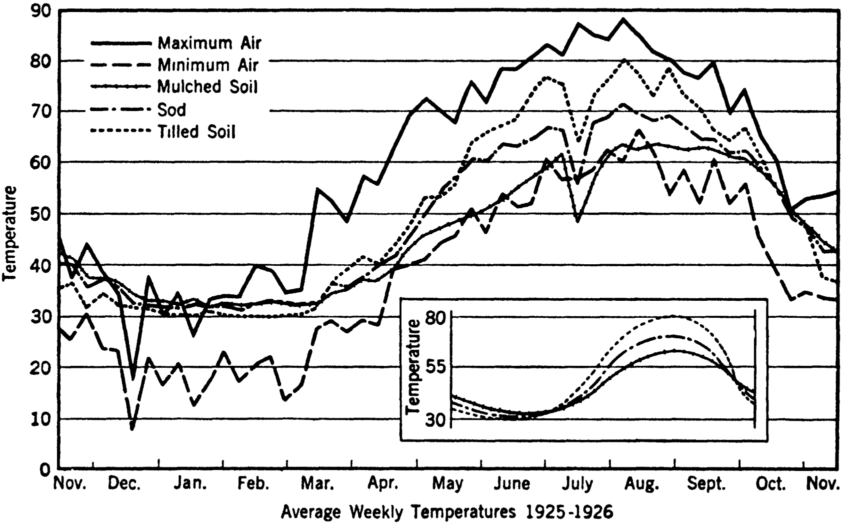

FIG. 46. Soil temperatures under different systems of culture.

It is customary in orchard experiments to determine soil nitrates and express them in parts per million (p.p.m.) and ammonia may also be determined. The difficulty of interpretation is that nitrates fluctuate constantly and it requires a large number of samples to give an index of their occurrence. Furthermore, the nitrates which are obtained in a sample represent the residue left after leaching and absorption by plants occupying the area.

Baker[6] points out that tree behavior cannot always be correlated with the nitrate nitrogen found in the soil. Some blocks of apple trees in cultivation and treated with a nitrogen fertilizer made a poor growth and the fruit was small even though nitrates were found in considerable amounts. Conversely apple trees growing in a bluegrass sod and receiving nitrogen fertilizer each year produced satisfactory results even though nitrates were seldom found. Fourteen-year old trees in bluegrass sod which received nitrogen made more growth and produced larger and better fruit than cultivated trees with or without nitrogen fertilizer during the latter years of the experiment, which was not true at first. This is an extreme experience, however.

In a pear orchard in Ohio nitrates were found to be rather low under both a straw mulch and alfalfa sod during much of the season. However, the mulched trees made an excellent growth and yield and showed no signs of nitrogen deficiency. Nitrates were comparatively high where tillage was practiced and also where a nitrogen fertilizer was applied to a bluegrass sod. In the bluegrass plots, however, the growth of the trees was much inferior to that made by the trees in mulch or by those cultivated with cover crops.

In Massachusetts, the results of a mulch on nitrate accumulation[9, 33] were most striking. In comparing the depressing effect of a straw mulch on soil nitrates as reported by Albrecht[1, 2] and others, particularly with annual crops, this Station found that the opposite was true except for the first couple of years. The plots included McIntosh and Wealthy apples and Bosc pears, planted in 1911. No fertilizer was applied to any plot. A cover crop was sown on the cultivated plots each year about the middle of summer. In 1925 the average of 20 weekly determinations showed the cultivated plot to average 10.1 p.p.m. of nitrates and the mulched one 37.9 p.p.m. The next season they averaged 19.6 and 127.5 respectively. In the latter year the nitrates ran as high as 452.5 p.p.m. under mulch, which explains why mulched orchards often do not respond to nitrogen fertilization.

Effect on moisture. Quite apart from the important relation of soil type to moisture, there is the effect of the culture on the amount of soil moisture available to the tree to be considered. In sections where irrigation is practiced or where rainfall is abundant this matter is of less or possibly of no moment.

Before definite observations had been made, it was assumed that trees in sod frequently were low in vigor and production because the grass competed with the trees for moisture. Later it was learned that the soil under sod may not be appreciably lower in moisture than a cultivated one, but that the unsatisfactory behavior of sod-grown trees was due to a low nitrogen supply.[5, 22, 26, 27] That moisture is more abundant where organic matter is naturally high and under mulches of any type, than under the reverse conditions, is generally recognized and experimentally established. Many data may be cited on these points, but a few experiments will suffice for the present purpose. It must be remembered that in any given experiment the same amount of precipitation is available to all plots but portions of it are lost by run-off, by percolation through the soil, by evaporation from the surface, and from transpiration from the plants growing on the land. Portions of it are retained by mulches, organic matter, and as a result of the physical properties of the soil itself.

In Pennsylvania [5] it was reported that "the per cent of moisture in all the sod plots was double that in the soil under tillage except where the plot was under continuous cultivation and even in this plot the soil had only about two-thirds as much moisture as in the grass plots."

An orchard in New Hampshire [22] showed consistently lower production and growth in a sod plot as compared with tilled ones. The soil was somewhat sandy and the original explanation was the low moisture content under sod. Determinations, however, showed surprising differences in moisture in favor of the sod which confirmed some earlier work by the Woburn Station, England.[10] The unfavorable behavior of the trees in sod was due to a deficiency of nitrogen rather than moisture.

In Indiana, soil-management studies were made in orchards under different systems of culture. During the early years of the experiment (1913–14) [44] the soil under sod was low in moisture as compared with cultivation or mulch. In the latter system the moisture was more than twice that in the straight grass land. In later years (1916–25) it was reported that there was "little difference in the moisture under the various plots." [16]

In the summer of 1939 drought conditions developed over rather wide areas of the Central West. In mid-September, determinations were made of the moisture content, the apparent specific gravity, and the calculated pore space in four different orchards and in a raspberry planting at Wooster, Ohio. Sod, mulch, and cultivation were compared. In all but one case the mulched soil had a distinctly higher moisture content than either sod or cultivation in the surface eight inches. In Orchard A, there was little difference, and at all points the moisture was extremely low. In the raspberry planting the soil moisture was strikingly higher under mulch than in tillage. The wilting percentage of this surface soil is about 7.5.

Again in Massachusetts [9] it was shown that moisture was distinctly higher under mulch during dry periods, but differed little at other times from the cultivated blocks of orchard. In 1925, the average of 20 determinations throughout the season, showed two cultivated areas averaged 24.9 per cent moisture (dry weight basis) and the mulched block 27.9 per cent. In 1926 it was 23.8 and 27.9 respectively.

The effects of different cover crops on nitrates and moisture in a peach orchard have been particularly noted at Beltsville, Maryland, on a sandy loam soil.[17] The soil is recorded as having a water-holding capacity of about 18 per cent and a wilting percentage of 8.2 per cent. The treatments included: manure, cultivation, lespedeza, sweet clover, soybeans, buckwheat, and crotalaria. In 1934 the soil moisture was reduced to the wilting percentage under both lespedeza and sweet clover down to two feet, from July 5 to August 11, and under soybeans from July 16 to August 2. At no time was the moisture in the cultivated plots within 4 per cent of the wilting percentage. Much the same situation obtained in 1936.

It is observed that the legume sods reduced the soil moisture by their active early season growth, while the summer covers did not affect moisture until much later in the season. Much the same situation holds with raspberries as with apple trees from the mulch standpoint. The organic matter may be maintained by adding manure, by mulching, or by growing cover crops. The New Jersey Station found that there was as much as 55 per cent more water in the soil under a mulch than in cultivation. This work was conducted on a "rather dry, gravelly loam" soil. The effect of the mulch on soil temperature was considered important since the raspberry is adapted to rather moist, cool soils. Salt hay was used at the rate of 6 tons per acre for the initial mulch and 2 to 3 tons more were added per acre subsequently.[15]

Effect on potassium. As indicated elsewhere, when potash is applied to many soil types it tends to be "fixed" and move downward at a very slow rate. It was surprising in the light of that fact to discover that potassium was found in the soil in large amounts beneath old straw or grass mulches, although no potash fertilizer had been applied.

At the Ohio Station determinations were made, both by a quick test [36] and later by determining the exchangeable potassium of the soil samples.[13] One orchard (A) had been mulched for 38 years with an estimated yearly amount of straw or other material of 150 to 200 pounds per tree. The other (C) had been mulched for 22 years. Adjacent cultivated blocks and untreated field plots were used as checks.

The quantitative results indicated that available potassium was quite high from 24 to 32 inches beneath the heavy mulch in both orchards. The entire cultivated area, as well as the unfertilized field plot, was notably low in available potassium. Intermediate to these extremes was the amount of available potassium present in the soil beneath the surface of old bluegrass sod near the other trees. The soil beneath two of the trees in the mulch system (C) had a content of approximately 1,000 pounds per acre of available potassium at a depth of 24 inches, while the soil beneath a tree 35 feet away in cultivation contained less than 175 pounds at the same depth [42, 43] (Fig. 47). This situation is quite understandable when it is realized that practically all of the potassium in plant tissue is water-soluble. Furthermore, it has been shown that the alternate wetting and drying of a mixture of a soluble potassium salt and certain soils at 70° caused a large amount of the potassium to be fixed by the clay fraction in a difficultly available form. But if soluble potassium is in contact with soil under continuous moist conditions such as would be found at the lower soil depths, fixation is very slow.[2, 23]

Truog and Jones [37] explain the fixation of potassium in their statement that, "When the exchange material is saturated with potassium and the material is then dried, which is supposed to bring the layers or plates of the crystal lattice together, the presence of the potassium offers such strong attraction as to prevent reexpansion of the crystal lattice and thus reëntrance of water and opening up of the crystal lattice, causing the potassium to become trapped in nonexchangeable form."

Wheat straw contains about 0.74 per cent K_2O, oat straw 1.50 per cent, and alfalfa 2.23 per cent K_2O. The nitrogen content is in the same order, while lignin is highest in wheat straw.

Effect of loosening soil about fruit trees. Many orchards have been set on soils that were shallow in the sense that a hard pan or impervious layer existed within a foot and a half, or even less, beneath the surface, or that a shale or rock foundation occurred at no great depth. That the orchardist should speculate on the value of breaking these up by some means is neither unreasonable nor surprising. Such efforts have been made by the use of dynamite, deep tillage tools, and by installing tile drains.

None of these attempts have met with much success in the eastern United States. One report stated that "the results are so variable as to cause one to suspect that the dynamiting has had little or no definite influence at all. The net effect in both experiments is rather against the shooting instead of in favor of it. At any rate, none of the present results would indicate any special value in the practice of dynamiting in apple orchards at least, and the same is true of the definite experimental results elsewhere.[34]

Recent results in West Virginia on attempting to "deepen" shallow, droughty soils yielded no beneficial results. The same is true of a deep tillage tool, the Killefer. "No useful purpose" was accomplished and it is not recommended at present to those who operate on such soils.[35]

Effect of cultural systems on the growth and yield of trees. It must be repeated that results from cultural practices, as well as fertilizers, depend largely on the soil with which one is dealing. With a fertile soil, well supplied with moisture, it may make little difference what sort of a soil management system is used provided the soil does not erode. Where moisture and nitrogen are limiting, even occasionally, the sod system is likely to prove unsatisfactory with the ultimate loss of trees, but with nitrogen fertilizer it often suffices for growth and production of apples, pears, quinces, and less frequently other fruits. Where moisture is limiting in seasons of scanty rainfall, there is no system equal to the mulch unless irrigation is available.

An experiment to determine the effect of cultural treatments on apple trees has been reported from Indiana and gives a picture of the results which may be expected over a large area of rather infertile land in the hill sections of the country. The varieties used were Grimes Golden, Jonathan, and Stayman Winesap. At the end of 15 years it was concluded that "growth and production have been greatest with trees receiving cultivation with cover crops. Where trees were in grass but receiving a heavy annual application of straw for mulch, growth and production were about equal to those under cultivation. Where trees were in grass without any mulch, growth was the lowest and production was also lowest. . . . Trees in cultivation for 8 years and then grown in grass during the second 5-year period made as slow annual growth as trees that had been continuously in grass, though the former were much larger. Trees that had been in grass for 8 years and which were given an annual application of straw mulch from then on, made annual increases in trunk girth equal to trees under cultivation or continuous straw mulch." [16]

The following data for Jonathan are representative of the results as a whole. (Table 10.)

TABLE 10. RESPONSE OF JONATHAN APPLE TREES IN GROWTH AND YIELD

(After Cullinan and Baker)[16]

Treatment	*Total*[a] *Gain 1916–20*	*Av. Yield per Tree in Lbs.*					*Total Yield 1916–20*
		1916	*1917*	*1918*	*1919*	*1920*	
Cultivation with cover crop	29.5	15.1	3.2	46.2	176.6	70.0	311.1 ± 17.7
Cultivation and sod	22.1	13.3	4.5	27.0	41.8	10.5	97.1 ± 18.1
Straw mulch	28.2	12.6	4.5	75.2	116.5	59.5	268.3 ± 32.8
Grass cut and let lie	24.7	1.0	.1	7.9	43.2	10.0	62.2 ± 7.5
Grass cut used as mulch, straw added	27.3	.8	.4	23.3	58.1	59.3	141.9 ± 16.6
Grass cut used as mulch	25.0	2.4	1.8	24.2	49.0	13.6	91.0 ± 15.6

[a] Growth in circumference in centimeters.

In the Ohio pear orchard, already referred to, substantially the same results were obtained as indicated for the apple in Indiana. While the trees were young, having been planted in 1929, and the records reported for 1931 to 1935, the results appeared significant and later results confirmed those reported. The gains in the cross-sectional area of the trunks of trees in the cultivated-plowed, cultivated-disked, and mulched treatments were not significantly different at the end of the 5-year period. The values were 5.82, 5.64, and 5.41 square inches, respectively. The gain of the trees in bluegrass sod was 62 per cent of that of the trees in mulch. The gain of those in alfalfa was 51 per cent of that of the trees in mulch. Likewise, the total weight of fruit from the trees in the cultivated and mulched treatment was not significantly different. The average per tree in the cultivated plots was 45 pounds, as compared with 43.7 from the trees in the mulched plot. Next in order was the yield from the trees in alfalfa, a total of 21 pounds per tree; the trees in bluegrass sod with added nitrogen produced the lowest average yield, 16.9 pounds. The trees were young and just coming into bearing.

Another experiment reported from Indiana,[6] which was carried on at Purdue University rather than in the southern part of the state illustrates the detrimental effects of cultivation on a soil where erosion is not a factor. At the end of 14 years "trees in bluegrass and receiving nitrogen are now making more growth and producing larger and better fruit than cultivated trees with or without a nitrogen fertilizer," which reverses their earlier results.

"Most of the fruit from the Grimes trees on the cultivated areas in 1935 was unmarketable because of small size. It was also severely russeted and unattractive. The fruit from the cultivated trees receiving nitrogen was even smaller than that from cultivated trees receiving no nitrogen, presumably because of the heavier set, but nearly twice as much fruit was produced per tree. Grimes fruit from the legume plots with or without a nitrogen fertilizer was of good size for the variety and attractive in appearance." By 1939 many of these cultivated trees had died while the adjacent mulched trees were in good condition.

The Ohio Station has carried on work with orchard culture since the beginning of the century. One orchard which was set in 1893 and the mulch system begun in 1899 is, at present, producing high average annual yields. The average annual production for 15 standard varieties in this orchard for a 28-year period has been 15.5 bushels per tree or in excess of 500 bushels per acre. In another orchard, set in 1915, the yields from the mulched and cultivated areas have been about equal. The average total production from 12 Stayman Winesap and 12 Delicious trees was 6,142.5 pounds in the cultivation-cover crop area and 5,851.7

pounds in the mulched area (through 1935). During the dry seasons the mulched trees have appeared better and the yield has been surpassing that in the cultivated block. During the 10-year period from 1928 through 1937, the average yield per tree in tillage was 619 pounds and in mulch, 629 pounds.

Soil management of stone fruits. The orthodox method of handling soil in orchards of the peach, plum, cherry, and apricot is tillage with or without cover crops. The peach and apricot seem to be particularly responsive to cultivation and the trees usually do not respond well in sod or mulch. Exceptions are reported, however, and an effort is being made to substitute some system whereby soil erosion will not take place. It is likely that a definite modification of the present system can be accomplished whereby the amount of cultivation will be materially reduced. It is better to cultivate young peach trees for at least two or three years before attempting a mulch or partial sod system.

That peaches are notably sensitive to any system wherein moisture and nitrates are at a low point during the period of active growth is shown in the work of Cullinan and Weinberger.[17] Both growth and yield are affected unfavorably by the legume covers as contrasted with cultivation and manure. (Table 11.)

TABLE 11. AVERAGE CIRCUMFERENCE GROWTH OF ELBERTA PEACH TREES, 1932 TO 1936, AND YIELD OF FRUIT, 1936

(*After Cullinan and Weinberger*) [17]

Treatment	*1932* *Cms.*	*1936* *Cms.*	*Yield per Tree Lbs., 1936*	*Number Peaches per Tree, 1936*
Manure and cultivation	6.0	35.3	151.3	678
Cultivation	6.4	32.0	58.1	288
Lespedeza	6.5	25.6	21.2	120
Sweet clover	6.6	24.3	21.1	127
Soybeans	6.8	28.9	47.2	242
Buckwheat	6.7	27.6	44.9	245
Cultivation	6.9	31.4	48.0	246
Crotalaria	6.8	28.0	48.5	257

These data are not encouraging to those who wish to grow peach trees in a legume sod. What additional benefit would accrue if these sod plots had been mulched and given additional nitrogen can only be surmised. The behavior of peach trees in other sections would give some basis for assuming the results would be much better and cultivation could be avoided. Such a program as the latter would only be called for on soils that erode.

With sour cherries in Michigan, Gardner showed that cultivation with cover crops proved much superior to an alfalfa sod. The sod trees received a half pound to a pound of nitrate of soda each year. At 9 years of age, the cultivated trees were nearly twice as large and were yielding almost twice as much fruit as the trees in alfalfa sod.[20]

The plum is much more tolerant of a sod or mulch system of culture than the peach. Many orchards that are commercially successful may be found where the mulch or partial mulch system prevails.

The cherry, both sweet and sour, thrives best under tillage. Exceptions of note are found to this, however.

Cost of various systems. The cost of management varies widely in different sections, depending upon the price of labor, materials such as mulch, seed for cover crops, management followed, and other details. No marked difference in cost obtains between cultivation and mulch, while the sod system entails little cost except mowing. When fertilizers are used in a sod orchard the costs are still below those in the first-mentioned system.

One set of data on an acre basis is supplied by the Indiana Station [16] as follows:

Cultivation: 5 cultivations, man, team, seeding, cost of cover crop seed	$29.42
Straw mulch: 2 bales of straw per tree @ $1.00 and cost of applying	36.55
Sod: Alone—grass cut	1.15
Sod: Grass cut and piled and 10 lbs. superphosphate and 10 lbs. nitrate of soda per tree square	19.75

In the Ohio experiments a record was kept of all production costs including picking and grading. During the last 10-year period of a 20-year test the cost per bushel on the cover crop plot was 53 cents and on the mulch plot 57 cents. During the last 4 years of this period 1931–34, the comparative cost of production was 38 cents per bushel for the cover crop and 39 cents for the mulch. This change was due to the increased yield per tree in the mulched area.

Grapes. Cultivation, with or without a sowed cover crop, is the prevailing practice with grapes. Vineyards which are not cultivated are usually considered abandoned. There are a few cases where mulching is practiced with good results provided the grape berry moth (*Polychrosis viteana* Clem.) is not a factor. In a study in

New York and Pennsylvania one area was noted where efficient cultivation and weed control was accomplished with only 11 hours of labor per acre per season. Most of these (Girard) vineyards were of good size, level, and the soil a sandy or gravelly loam.[31]

The observation was made that these results were secured because of the maximum use made of the disk and harrow and the minimum use made of the plow, cultivator, horse hoe, and hand hoe.

The prevailing practice is to cultivate a vineyard about twice a season. Partridge [29] recommends shallow cultivation, and suggests that a harrow is a better tool than a disk on sandy soils and the latter on loams. The horse hoe is a useful implement in the vineyard as it can be manipulated close to and under the vines, thus keeping the rows clean. In New York it cost more to horse hoe an acre than to disk, harrow, or gang plow. Some injury to surface roots is sometimes reported from the horse hoe.

Cover crops are usually recommended for a vineyard. Rye, rape, vetch, oats, buckwheat, and millet are commonly used. The cost of seeding is small, averaging about $2.00 per acre. The seeding is usually done by August 1. In Michigan vineyards seeded to cover crops from 1924 to 1928 yielded 8 per cent more than neighboring vineyards not so treated.

Small fruits. Berries of various kinds are usually cultivated, and the additional use of cover crops is recommended. The outstanding cultural provision seems to be the maintenance of a favorable organic matter and moisture supply. With these two factors goes the third one, good soil drainage. As indicated elsewhere, these provisions are more important than fertilizer formulas. Irrigation of dry soils is usually an economic procedure.

During recent years some striking results have been secured from mulching raspberry plantations. This seems to be notably true as one approaches the southern limit for this fruit, where the soil temperature is high during the growing season. It is likely to have a wider use in the future.

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FERTILIZERS AND MANURES FOR THE ORCHARD

The supplying of nutrients to fruit trees in the form of artificial fertilizers, whether in organic or inorganic form, introduces a subject on which there is some difference of opinion. However, much experimental evidence and practical experience are available, and in many sections the results can be predicted with considerable certainty. The original conceptions of this problem were based largely on the findings of the chemists, for it seemed logical to conclude that the elements found in the plant and its products in greatest amounts were the ones to apply to the soil in like proportions. This doctrine led the horticulturists astray for a time, for, logical as it may seem, such a theory does not take into consideration the mechanical or physical condition of the soil, the inheritance of the soil in regard to each element, or the important role of microörganisms to soil fertility and the associated factors of temperature, moisture, and soil aeration. Obviously, the amount of fertilizing that trees require depends basically on the native fertility of the soil together with its physical condition and its moisture-supplying power. The lowest level of each element at which fruit trees will still thrive and show no visible signs of deficiency, and the effect of a luxury consumption of any given element have not been determined for fruit trees. Hence, a wide variation in the practical results of fertilizing orchards is to be expected, especially in the relative length of time that will be necessary to produce comparable results.

Criticisms of orchard experiments. Many of the experiments on orchard fertilization have been seriously criticized from several points of view, *viz.:* The soil in some of the experimental orchards has been exceedingly variable, and yet no account has been taken of that fact in recording the effects of the various fertilizer treatments.[8] Fruit trees, particularly large apple trees, vary exceedingly in the size of the crop they produce, as well as inherently even if the trees are of the same size, and averages for any given plot may be misleading. When buffer rows have not been maintained between the plots, there has not infrequently been "cross feeding" which would seriously modify the results. Missing trees in an orchard may give certain advantages to those adjacent to the open spaces, and also diseased, winter-injured, or subnormal individuals may not give a result representative of the treatments used. Differences of topography may give an advantage to certain plots over others. This is because of unequal frost action, drainage, and susceptibility to disease, any one of which reasons may play a large part in the results secured. Allowances for these inequalities may not be made or they may not even be mentioned. Unwarranted conclusions have been drawn of the value of a single element by subtracting the performance of a two-element treatment from that of a three-element one. Perhaps there is an important factor of variability through the use of seedling roots for understock. Many other suggestions or criticisms might be enumerated, all of which would be justifiable in critically examining this problem.[3, 30]

Because of the small number of individual trees per acre it is difficult to select uniform conditions for an orchard experiment. Nevertheless, much has been learned from this more or less empirical work, and greater refinement of methods has followed as a result.

Nutrients removed by fruit trees. While fruit trees absorb from the soil a number of elements, several of which are essential for the maintenance of growth and fruiting of trees, nitrogen only is widely used in most orchard sections. Other elements are essential in certain limited areas, as discussed later, but the student should be familiar with the draught upon the soil of the three most commonly considered; namely, nitrogen, phosphorus, and potassium. The calculations by Heinicke may be taken as representative although data from different sources may vary rather widely.[29] (Table 12.) These estimates were based on records obtained in an orchard which was well supplied with nitrogen. The new tissue included new shoot growth, new spur growth, or new layers of wood and bark on all twigs, branches, and trunks, as well as the tissue of the root system. He found that the dry weight of all this new tissue amounted to approximately three times the dry weight of the total leaf area. The figures refer specifically to potassium (not K_2O) and to phosphorus (not P_2O_5).

From these figures it will be noted that the amounts of nitrogen and potassium removed are about equal, while the amounts of phosphorus removed are only one-seventh to one-eighth as much. This in itself would mean little, as it depends upon the total supply in the soil as to the amounts that would need to be applied.

TABLE 12. PLANT FOOD AND NUTRIENT REQUIREMENTS FOR A MATURE FRUIT TREE PRODUCING 25 BUSHELS OF FRUIT (LBS. PER YEAR)

(*After Heinicke*) [29]

Item	*Fruit*	*Leaves*	*New Tissue*	*Total*
Dry weight	202.50	65.80	197.40	465.7
Carbohydrates	192.40	62.50	187.50	442.4[a]
Nitrogen	0.63	1.38	1.88	3.9
Potassium	1.53	0.79	1.18	3.5
Phosphorus	0.12	1.10	0.27	0.5

[a] An additional 100–125 pounds is lost by respiration.

Magness and Regeimbal [38] report a comprehensive study of the nitrogen requirement of apple trees in full bearing. Their data indicate "a necessary intake of from 1.5 to 1.75 pounds actual nitrogen per tree per year. Of this amount, almost 1 pound is permanently removed from the orchard soil, while from 0.5 to 0.75 pound ultimately returns to the soil with the decay of blossoms and leaves. If less than these amounts are available, it will be reflected in reduced tree growth, reduced leaf area, and reduced production. Quantities of nitrogen greatly in excess of these amounts may result in fruit high in nitrogen content and consequently of poor color. . . . For trees very low in nitrogen, considerably greater quantities would need to be taken into the tree for 1 or 2 years to build up the storage reserve to the point found in these investigations, which are based on trees receiving ample annual applications of nitrogeneous fertilizers." The following table (Table 13) summarizes these results.

Fruit trees differ from other crop plants. It must be recognized in dealing with fruit trees that the problem is essentially different from that obtaining with many other plants. This is particularly true because of the fact that trees are perennial plants, occupying the land for a quarter to a half century, or longer. The root system is extensive and is found in the subsoil as well as the surface soil, the depth depending largely upon the character of the soil. The fact that potassium does not become a part of the organic material comprising plant tissue, as is true with many other elements, but may possibly be reutilized in its catalytic role may account in part for

TABLE 13. ESTIMATED NITROGEN REQUIREMENT OF 25-YEAR-OLD APPLE TREES IN GOOD VIGOR TO MAINTAIN THEM IN THAT CONDITION

(After Magness and Regeimbal) [38]

Tissue	*Estimated Wt. per Year (Lbs.)*		*Approximate Nitrogen Content Per Cent Dry Weight*	*Pounds Nitrogen Permanently Removed from Soil*	*Removed from Soil but Ultimately Returned*
	Fresh	*Dry*			
Fruit (exlusive of seeds)	600	100	0.23	0.23	—
Seeds	—	1.8	5.5	0.10	—
Abscissing blossoms	14.0	3.0	3.0	—	0.09
Leaves					
Midsummer	200	70.0	2.2	—	—
At leaf fall	—	60.0	1.0	—	0.60
Wood growth	133	80.0	0.15 [a]	0.12	—
Bark growth	33	15.0	0.6 [a]	0.09	—
Root growth	130	65.0	0.45 [a]	0.30	—
Total				0.84	0.69

[a] "Residual" nitrogen considered not available for translocation and reutilization.

the frequent lack of response secured from this element. Even relatively small amounts in the soil appear to be adequate with such an extensive root system as fruit trees possess.[60] The same appears to be true of phosphorus.

Analysis of the soil as a guide to fertilizer practice The question arises as to whether a chemical analysis of the soil would be a guide to fertilizer practice. While such information is desirable it rarely follows that such an analysis of itself provides a reliable guide. Growers frequently wish to obtain such analyses and have been hopeful that the "quick tests" which have been devised for the different elements would prove useful. But there seems to be no reliable substitute for field trials and the interpretation of tree appearance and behavior.

While it is true that trees on impoverished or infertile land will usually be notable for their paucity of both growth and yield, yet if the physical condition of the soil is favorable, a good growth may be secured out of all proportion to what would be expected from ordinary farm crops on the same land.

Response of orchards to fertilizers. No generalization can be made regarding the fertilization of orchards. As stated before, it depends upon the starting point (i.e., the native fertility of the soil) and the cultural methods used as to whether there is need for additional nutrients to those already present. Also if insects and diseases are abundant, or the soil is poorly drained, it makes little difference what kind of fertilizers are used, since a positive response from them is unlikely. It then becomes a question of what limiting factors exist under a given condition. Even though soil conditions are favorable, nitrogen and moisture are likely to be limiting in more orchards than other factors. These in turn are related, at least to some extent, to the supply of organic matter.

After 7 years of fertilization in a bearing orchard, the New York Station concluded that "the trees in this experiment would have been practically as well off had not an ounce of fertilizer been applied to them." At the end of 20 years it was observed that neither manure nor any kind of fertilizer was of definite benefit in this cultivated orchard.[28] In other locations positive results are almost immediate, as indicated later.

The need for fertilizers or manures may be judged by the experienced orchardist from the color and size of the leaves, the length and diameter of shoots, and crops of fruit produced.[13, 51] Excessive growth and extremely large and dark green leaves are no more to be desired than the opposite condition. In some cases certain deficiency symptoms of fruit or foliage will indicate lack of such "rare" elements as zinc, copper, manganese, and boron.[12]

Young trees may not, and often do not, respond to applications of nitrogen or other elements. Older trees on fertile soil and under tillage with cover crops may be slow or never respond in any measurable way. Likewise, trees under a heavy mulch may have sufficient nutrients and fail to respond to additional amounts applied to the soil. In general, the stone fruits, particularly the peach, should be fertilized with nitrogen each year after they come into bearing. Potassium and occasionally phosphorus or some other element may be deficient in some soils and give an excellent response when applied. The apple, when grown in sod, should usually be fertilized at least with nitrogen unless animal manures are applied in sufficient quantities. The same would be true of the pear if it were not for the danger of blight. All of this means that in case of doubt the only definite answer can be obtained by a local test. If a response is secured from any of the elements or a combination of them, its use should at once be extended to the remainder of the orchard on like soil. Under many conditions, very large financial returns may be secured from the use of fertilizers; it is not wise to delay applying them until such marked results are secured as on some of the impoverished soils, but rather to maintain continuously a vigorous condition of the trees.

Role of the elements nitrogen, phosphorus, potassium and calcium. Chemical analyses show that fourteen elements make up the bulk of most plants. The various elements of which a plant is composed will, of course, depend upon the species of plant and upon the composition of the soil upon which it is grown. Of these various elements, in most cases only four need be considered as important soil amendments.

Nitrogen is found almost entirely in organic combination in fruit plants, particularly the apple and other tree fruits. It enters into the structure of protoplasm, chlorophyll, amino acids, proteins, and alkaloids. The absence of sufficient nitrogen results in small yellow leaves, reddish bark, and stunted growth even though other factors are favorable. On soils low in fertility, applications of nitrogen have been of great benefit in the increased set of fruit. An excess of nitrogen produces heavy growth and often delays ripening processes and conditioning of the tree for winter.

Phosphorus is essential for the formation of nucleic acid, nucleoproteins, and lecithin which are present in almost every living cell. Practically all phosphorus is absorbed in the plant in the form of phosphates. A deficiency of phosphorus, if it be the limiting factor, will be evident in the plant by: purple midrib of leaves (in some cases), dull gray-green leaves, premature defoliation, reduced lateral root growth, and delayed maturity.

The function of potassium in the plant is not definitely known. It is believed by most investigators to assume the role of a catalytic or condensing agent in the formation of numerous organic compounds, particularly the synthesis of carbohydrates in the process of photosynthesis. A lack of potassium in plants may be seen as: slender stems and roots, shortened midrib, spotting and edge burning of leaves, less resistance to disease, and a short vegetative phase. It has been found in many plants that cell division is seriously inhibited by a lack of potassium.

The part calcium plays in the growth and development of green plants is not entirely understood. It is known that calcium is a component part of plant structures, influences translocation of carbohydrates, influences absorption of other ions, and reduces the toxic effect of other elements and organic acids. Some effects of calcium deficiency upon the observable behavior of plants is seen in: yellow terminal growth while the lower leaves remain green, short apical meristems, short stubby roots with dead ends, and stunted, stiff woody plants.

The Major Elements Concerned

*Nitrogen.** Nitrogen occupies a more important place in orchard fertilization than any of the other nutrient elements. It is utilized to a great extent by bacterial growth as well as in the tree growth and fruit production. Bacteria play an important part in changing complex forms of nitrogen to forms which are available to the tree. Certain types of bacteria are able to utilize nitrogen from the air, changing it into available forms. Such bacteria are commonly found in the root nodules of legumes. The amount of nitrogen in the soil fluctuates widely during the year, the amount present at any one time depending on the above factors as well as on soil and climatic conditions.

Nitrogen is usually supplied to the soil in the nitrate or ammonia form. With many organic fertilizers such as Cyanamid, urea, tankage, or fish scrap, the nitrogen is in a form unavailable to the tree and must be changed to an available form through the action of bacteria or certain catalytic agents. In most soils these are present in sufficient quantities to effect the change. The transformation is frequently slow, however, and for this reason, these materials are more slowly available than the water-soluble nitrate or ammonia forms.

Value of nitrogen in orchards. Prior to 1910 there were few experiments in orchards to guide the grower in the use of fertilizers. Potassium was considered of greatest importance and nitrogen to be detrimental in that the stimulation of growth was thought to be antagonistic to fruitfulness. While the value of nitrogen for fruit trees was not really unknown, its use had not found general acceptance. Some trials were made in California to determine the value of spraying dormant trees with a solution of nitrate of soda to shorten the rest period. The treatments resulted in advancing the bloom period by several days, and the trees showed an improved growth, color of foliage, and yield the ensuing season.[4] The work was repeated in Oregon both with a canvas beneath the trees to prevent the solution entering the soil, and without it. Where no covering was used the trees showed a marked improvement which later was recognized as characteristic of nitrogen fertilization. About that time several comparative fertilizer tests were inaugurated almost simultaneously which resulted in an immediate demonstration of the value of nitrogen as compared with phosphorus and potassium. The experiments in Ohio, Oregon, Pennsylvania, and elsewhere influenced practice for the next quarter of a century, in that a "nitrogen only" program has been generally followed. The value of other elements are now being shown in certain more-or-less restricted areas as described later.

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* For a monograph on the role of nitrogen the student should consult: Nightingale, Gordon T., 1937. The nitrogen nutrition of green plants. Bot. Rev. 3:85–174.

Nitrogen generally enters the tree as the nitrate (NO_3) or inorganic form.[20] It may be synthesized (with carbohydrates) to form amino acids at any place within the tree and not necessarily (and not commonly) in the leaves. In addition to being a component of the molecules of proteins and amino acids it is a part of the complex molecule of chlorophyll.

That nitrogen affected the "set" of fruit within a few weeks after it was applied was early demonstrated, particularly on trees of low vigor. Ballou[5] seems to have been one of the first to report this phenomenon. An orchard of 20-year-old Rome Beauty apples which had produced but one crop of fruit because of its extremely low vitality, was fertilized in part about the middle of April. "The trees bloomed rather uniformly over the entire orchard, but the blossoms were unusually small and apparently lacking in vitality. However, after the petals of the blossoms had fallen, the little apples on the fertilized plots where nitrate of soda had been included clung to the fruit spurs and began to grow in a perfectly normal manner, while most of the embryo fruits on the adjoining unfertilized plots withered and dropped from the tree just as the apples had been doing throughout the past life of the orchard." At picking time of this first year one row of 8 trees which was fertilized with 5 pounds of nitrate of soda and 4 pounds of superphosphate produced 21 barrels of fruit, while the adjoining untreated row yielded 9 barrels. The widespread fear that nitrogen stimulates exclusively vegetative growth at the expense of fruit bearing, while not entirely groundless, is much exaggerated. In England, it is recorded that apples in particular are frequently overnitrogenous without the addition of nitrogen. This condition results in overvigorous growth, accompanied by lack of quality, stunting where potassium is low, and increased susceptibility to canker and scab.

Carriers of nitrogen. Various carriers of nitrogen, both organic and inorganic, have been used for orchard work, and others are likely to appear from time to time. This is particularly true since synthetic compounds are on the increase and the process of combining the nitrogen of the air with calcium, sodium, and other bases has assumed large commercial proportions.

Organic vs. inorganic fertilizer. The term organic as applied to chemicals originally referred to the carbon compounds in or derived from organisms, but since many of these are now synthesized in the laboratory, the term has been broadened to include all compounds of carbon except carbonates. The terms natural and synthetic organics are frequently used to differentiate between the laboratory and natural products. Cyanamid and urea are synthetic organics whereas fish scrap and tankage are natural organics. For the most part, the natural organic materials may be considered together and the synthetic organics with the inorganic materials considered as another group.

In comparative tests on the use of organic fertilizers, such as dried blood, tankage, and cottonseed meal, and such inorganic materials as nitrate of soda, sulfate of ammonia, and superphosphate, the evidence has usually indicated that the inorganic materials are to be preferred. The latter are quicker acting and result in larger production of fruit, field crops, and flower crops. There is some tendency to use a combination of the two sources, and many individual growers prefer this practice.

A 5-year experiment in an apple orchard badly in need of nitrogen resulted in an average yield of 205.8 pounds of fruit per tree from 5 pounds of nitrate of soda, and 93.8 pounds from 5 pounds of tankage and 5 pounds of bone meal. The superphosphate and muriate of potash may be ignored in this case since they produced no results in other similar experiments.[5]

One 3-year test with Elberta peaches resulted in an average of 137 pounds of fruit per tree from 3.9 pounds of nitrate of soda, 128 pounds from 3 pounds of sulfate of ammonia, 82.9 pounds from 7 pounds of tankage and 5 pounds of bone meal (the equivalent in nitrogen of the above), and 47 pounds per tree from an untreated plot.[26]

Sodium nitrate. Large quantities of sodium nitrate, $NaNO_3$, (Chile saltpetre) commonly carrying 16 per cent nitrogen, have been imported from Chile where large natural deposits occur. A synthetic product is now on the market also. Where a very quickly available form of nitrogen is desired, sodium nitrate is probably the best of the nitrogen carriers. The nitrate from sodium nitrate rather readily leaches from the soil, yet it is surprising how well it serves the purpose even when applied in the autumn.

Nitrate vs. Ammonia. The relative value of fertilizers carrying nitrogen in the nitrate form as compared to those carrying it in the ammonia form has been studied for some time. Certain individual characteristics exist in these materials which make them distinctly different. The nitrate forms of nitrogen are water soluble, very quickly available, usually carry an element (Na,Ca,K) which has a tendency to decrease soil acidity, but are rather easily leached. The ammonia forms are a little more slowly available, less likely to be leached, and have a tendency to increase soil acidity.

The results of comparative tests between fertilizers carrying nitrogen as nitrate, and those carrying the ammonia form have not always been in agreement. It was formerly thought that plants could utilize nitrogen in the nitrate form only, and that ammonia nitrogen must be oxidized to the nitrate form before the plants could absorb it. Recently it has been shown that many plants can utilize ammonia as well as nitrate nitrogen. Evidence from sand culture experiments points to the fact that the utilization of nitrate nitrogen by at least some fruit trees is most efficient when the culture solution is relatively acid, whereas ammonia may be utilized directly when the culture solution is alkaline. With apple trees, best growth was obtained when nitrate was supplied at pH values of 3.5 to 6.5. Ammonia gave best growth at pH values above 6.5, and it was thought that it was utilized without oxidation at this degree of acidity.[7, 54] While the use of sand cultures is of value in a critical study of certain plant responses, care should be used in interpreting results from the standpoint of actual field conditions.

From orchard fertilizer experiments, it would seem that there is little difference in the results from the use of nitrate and ammonia forms of nitrogen. Where the orchard is suffering severely from lack of nitrogen, or where a very quickly available form is needed, the nitrate form has given slightly better results for 1 or 2 years. Schrader and Auchter, and others, found with trees of low vigor growing in sod, that nitrate-fertilized trees made a better response in yield than ammonia-treated trees amounting to from 1½ to 5½ bushels the first year, both forms increasing the yield considerably over check trees. They found that the difference in tree response between nitrate and sulfate became less each year.[48]

Knowlton and Hoffman, using nitrate of soda and sulfate of ammonia in four different experiments, found that one material was not superior to the other if applied about two weeks before bloom, but that nitrate was superior if the applications were delayed until the trees were in bloom.[35]

Calcium cyanamide. Calcium cyanamide, $CaCN_2$, is a synthetic product containing 19–22 per cent nitrogen. Most of the calcium cyanamide used in the United States is manufactured in a plant at Niagara Falls, Canada, and is sold under the trade name of Cyanamid. The granular form contains 21 per cent nitrogen and the pulverized 22 per cent.[49]

The use of this material for orchard fertilization has been increasing markedly due in part to the low cost per unit of nitrogen, and also because it contains a considerable amount of active lime. It is quite slowly available and is not leached from the soil to any great extent. Because of this, fall applications have been recommended. On sandy soils deficient in organic matter and moisture, spring applications on stone fruits have resulted in severe foliage burning, and it is never recommended under these conditions. If handled properly, however, it makes a satisfactory source of nitrogen for most fruits. Where the soil contains organic matter and there is sufficient moisture, either fall or early spring applications are entirely satisfactory.

The nitrogen of calcium cyanamide is in an unavailable form and must first be mineralized in the soil, e.g., be converted to ammonium salts or nitrates. The older views concerning its decomposition are that it is changed rather readily to urea probably through the action of certain inorganic catalysts, and then to ammonia through bacterial activity. These changes take place most readily in a slightly acid medium in the presence of moisture, organic residues, and the colloidal fraction of the soil. A few simple equations illustrate the reactions in the soil:

$$\underset{\substack{\text{calcium}\\\text{cyanamide}}}{CaCN_2} + 2H_2O \longrightarrow \underset{\substack{\text{hydrogen}\\\text{cyanamide}}}{H_2CN_2} + \underset{\substack{\text{calcium}\\\text{hydroxide}}}{Ca(OH)_2}$$

$$H_2CN_2 + H_2O \longrightarrow \underset{\text{urea}}{CO(NH_2)_2}$$

$$CO(NH_2)_2 + 2H_2O \longrightarrow \underset{\substack{\text{ammonium}\\\text{carbonate}}}{(NH_4)_2CO_3}$$

$$(NH_4)_2CO_3 \xrightarrow{\qquad\qquad} \underset{\text{ammonia}}{2NH_3} + CO_2 + H_2O$$

More recently it has been shown that microörganisms (bacteria and fungi) are doubtless the most important of the factors involved in its decomposition, although catalysts also play a role. In the presence of suitable organic material as a source of energy, they quickly and easily decompose hydrogen cyanamide with an average concentration (of 0.45 per cent cyanamide) and utilize it as a source of nitrogen. The decomposition has been promoted through greater numbers of microbes and by increasing amounts of carbohydrates as energy material.

According to this author, the first product of hydrogen cyanamide hydrolysis was urea. This was ammonified and nitrified in the soil as secondary reactions.

On this basis it can be explained that Cyanamid works best on soils which are high in organic matter and are biologically most active. Conversely it cannot be recommended on sandy soils low in organic matter.[47]

In cases where it is applied on very dry or frozen soils it may on occasions become polymerized and rendered highly insoluble.

Sulfate of ammonia. Sulfate of ammonia $(NH_4)_2SO_4$ commonly contains 20.5 per cent nitrogen and has probably been used to a greater extent in orchard fertilization than any of the other nitrogenous fertilizers. It is readily soluble, but in a form not easily leached from the soil, and has been one of the cheaper sources of nitrogen. It is a synthetic material manufactured by utilizing the nitrogen from the air.

Ammonium sulfate has consistently given good results in orchards which have needed applications of nitrogen. Its use on soils with a high pH value is usually recommended since it is thought that the ammonia is utilized better than nitrate under those conditions. Ammonium sulfate is used directly without the necessity of conversion of ammonia to nitrates in the soil. The response in the tree is as rapid as when nitrates are used.

Phosphorus. Phosphorus is rather low in many orchard soils and in animal manures, but is used in less amounts by fruit trees than either nitrogen or potassium (in about the relation of 4N, 1P_2O_5,

$4K_2O$). The data in regard to this element are rather unsatisfactory and inconsistent in most orchard experiments, either when used alone or in combination with other elements. In a few cases positive results have been reported. This element is of value in increasing the stand and growth of legumes, and indirectly in improving an orchard soil.

Carriers of phosphorus. This element is obtained in various natural and manufactured forms. Phosphatic rock is one containing one or more calcium phosphate minerals of sufficient quantity and purity to warrant its use. Commercial phosphate rock as produced in the United States carries about 66 to 77 per cent equivalent of tri-calcium phosphate.

The term phosphoric acid in fertilizer practice refers to the combination of phosphorus and oxygen expressed by the formula P_2O_5. Salts of orthophosphoric acid (H_3PO_4 or $P_2O_5 \cdot 3H_2O$) are used as fertilizers. These include sodium, potassium, ammonium, and calcium phosphate. None of these is used to a large extent except calcium phosphate or phosphate of lime.

Superphosphate (referred to in the older literature as acid phosphate) is the chief material supplying available phosphorus in fertilizers. It is produced by the reaction of equal amounts of finely ground phosphate rock and sulfuric acid. A mixture of monocalcium phosphate, dicalcium phosphate, and gypsum is formed which is called superphosphate. The following reactions indicate the formation of this material.

$$Ca_3(PO_4)_2 + 2H_2SO_4 \longrightarrow \underset{\substack{\text{monocalcium}\\ \text{phosphate}}}{CaH_4(PO_4)_2} + \underset{\text{gypsum}}{2CaSO_4}$$

$$Ca_3(PO_4)_2 + H_2SO_4 \longrightarrow \underset{\substack{\text{dicalcium}\\ \text{phosphate}}}{Ca_2H_2(PO_4)_2} + CaSO_4$$

The available phosphoric acid in superphosphate varies from 16 to 27 per cent. The most common form of superphosphate contains 20 per cent available phosphoric acid. Double, Treble or Triple superphosphate are names given to the same product containing 2½ to 3 times as much available phosphoric acid (P_2O_5). The formation of the product is much the same except that phosphate rock is treated with phosphoric instead of sulfuric acid, thus eliminating the formation of gypsum, $CaSO_4$, according to the reaction $Ca_3(PO_4)_2 + 4H_3PO_4 \longrightarrow 3CaH_4(PO_4)_2$.

Some new forms carrying high percentages of phosphoric acid are appearing but have not yet been tried under orchard conditions. Calcined rock phosphate (37.4 per cent P_2O_5); fused rock phosphate (29 per cent P_2O_5); and calcium metaphosphate (63 per cent P_2O_5) are examples.

Organic phosphates have been introduced by Stewart and Spencer of the University of Nevada. One contains 23.1 per cent P_2O_5 and another one 31.8 per cent. The special merit of these glycerophosphates is in their tendency to remain soluble and penetrate to greater depths in the soil than other forms. Should phosphorus become needed for orchard lands, these newer forms should prove valuable.

That the phosphorus in the usual mineral form is quickly "fixed" in the surface of many types of soil is well known. In a survey of 27 orchard soils in Ohio to which phosphorus had been applied, little of it had percolated to a greater depth than 3 inches where the land was in sod. In cultivated areas it was found to the depth of its mechanical distribution. In one orchard where there was an interval of 14 years since the last application of this element (5 pounds superphosphate per tree) the residuum in the surface inch or two was clear.[25]

Exactly the same situation was found in a grape experiment in Ontario after 8 years of treatment. For instance, where the amount of readily available phosphorus was from 20 to 30 p.p.m. in the surface soil at the beginning, it was 60 to 90 p.p.m. in 8 years after 5,600 pounds of superphosphate per acre had been applied. In the subsurface soil it was around 30 p.p.m. at first and the same at the end, with one exception where it had risen to 54.[55]

Both phosphorus and potassium exist in the soil in two distinct forms, from the standpoint of the grower, "fixed" and "available." Plants can use the fixed material very slowly. It is the available or "exchangeable" form which is roughly determined by the "quick test."

Potassium. Potassium is used by fruit trees in relatively large amounts. This led to the earlier teachings that potash was the first essential in fertilizing trees, and this is conspicuously true in certain areas at the present time. But most fruit soils are sufficiently well supplied with this element to make application of it unnecessary. Even where other crops respond definitely to potassium treatments fruit trees may show no improvement whatever. Whether fruit trees are able to absorb potassium more readily than other crops, whether it is largely a matter of the greater depth of the root system, or whether it is some other factor operating does not seem to be clear. It should also be pointed out that peach trees use larger relative amounts of this element than apples. It has been reported that, with 9-year-old trees, peaches contained 4 times as much K_2O as apples. In line with this fact it is shown by several investigators that along the Eastern Coastal Plain many peach orchards are now showing response to potash, with visible potash-deficiency symptoms corrected by potash applications. Apples in these same areas generally do not show recognizable symptoms of potash deficiency.

These relative amounts of available potassium were compared to a "low" content prior to treatment determined by a quick test.

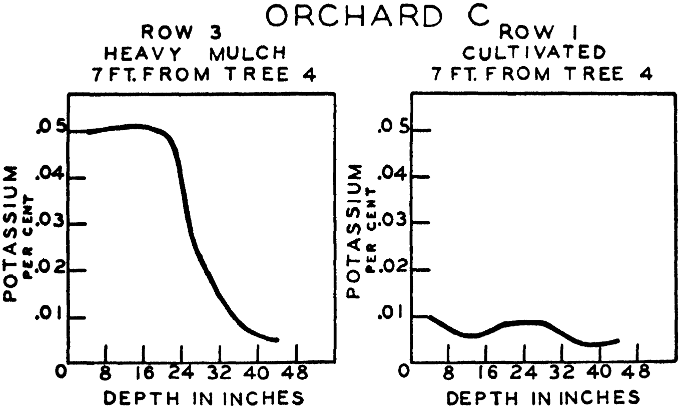

FIG. 47. Graph showing exchangeable potassium in per cent beneath a mulched and a cultivated apple tree.

In other words, there had not been any downward translocation of available potassium below 4 inches. At the end of 10 years there had been an additional downward movement, but the rate of application had been approximately doubled. Potassium at the end was "high" to "very high" to a depth of 6 inches, but still not deep enough to reach the majority of roots in a silt loam soil.[60] (Fig. 47.)

With a better understanding of the phenomenon of base exchange the immobilization of soluble potassium in soils has been studied from the standpoint of its being nonreplaceable as well as its being insoluble in water. Joffe and Kolodny have shown that aluminum and iron phosphates are instrumental in fixing a high percentage of KCl added to a soil, particularly at 70° C. Alternate wetting and drying of a soil accentuates the process.[34, 39]

It is well known that in England and other European countries, in New Zealand and Australia; at Vineland, Ontario; Santa Clara, and Chico Valleys, California, on the sandy soils of North and South Carolina, and a few other places in the United States potassium is the chief limiting element of fertility. In other orchard sections there are successful growers who believe that the use of a complete fertilizer is better practice than nitrogen alone and regularly use it without any particular data to support the practice.

Nevertheless, it is true that most experiments in this country have failed to show any profitable response from this element and usually no response whatever. Hence, experiment stations have been conservative in recommending its use, particularly since the economical management of the industry is paramount.

Wallace [58] has repeatedly pointed out the need for adding potassium to the fruit soils of England, and the typical symptoms of leaf scorch and stunted growth. Hoblyn and Bane,[32] working in England, have shown the response of 12-year-old trees growing under cultivation and unmanured from the time they were planted. "Sulfate of potash effected a remarkable recovery in shoot-growth, amount of crop, and size and quality of the fruit in the second season. Nitrogen by itself was generally detrimental, with potash it further increased the growth and cropping but always reduced fruit color." The usual treatment on English soils is 200 to 500 pounds per acre. Sulfate is preferred to muriate of potash.

Some investigators have reported that the texture, quality, and keeping quality of fruit have been improved by potash applications even though no improvement in growth or yield was noted. This in itself would be important, and careful tests should be made to determine these points on various soil types.

Amount of potassium necessary for fruit plants. The question arises: what is the level of available potassium in a soil or the amount of potassium in a plant tissue at or below which fruit plants will show symptoms of deficiency of this element. Batjer and Magness [9] have made a survey of orchards in several widely separated fruit sections of the United States. They report results from sand culture with York Imperial apple trees which are close approximations of results from the field as follows. "It was found that visible symptoms did not occur in trees receiving 10 parts per million or more of potassium in the nutrient solution. Growth of these trees increased, however, with increased potassium, when all other nutrients were abundantly supplied, until a concentration of over 60 parts per million was reached. The potassium content of the leaves was found to be closely correlated with both the growth of the trees and the amount of potassium supplied in the nutrient solution. In these tests, vigorous growth occurred in trees having above 1 per cent potassium in the leaves, although the maximum growth did not occur until the potassium content of leaves was above 1.7 per cent. Leaves of trees showing definite deficiency symptoms contained less than 0.7 per cent potash. These results suggested the value of analysis of the leaves of fruit trees as an indication of the potassium supply available to the trees. It is of course recognized that the actual quantities found necessary for good growth in the juvenile trees used in the nutrient experiments may be very different from the quantities necessary for bearing orchard trees." Dunkle, *et al.*, find from an extensive investigation in Pennsylvania that "Leaf analyses did not correlate with the replaceable soil potassium but in some cases gave indications of the effects of potash application which could not be detected by exchange analyses." They comment that "This might be expected since the percentage of any element present in tissue is expressed upon the total growth which in itself depends upon all growth factors, nutritional and otherwise." [18]

From the field survey Batjer and Magness report that "Orchard trees of York Imperial and Jonathan having under 1.0 per cent potassium in the leaves, and Delicious and Rome Beauty having under 1.5 per cent would seem most worthy of study from the standpoint of response to potash applications. If such trees do not respond, there would seem to be little chance that orchards running much higher would do so."

Wander [59] made spectrographic analyses of leaves from fruit trees known to be deficient in potassium and from others which were apparently not deficient. He found an apple tree grown in sand culture showed 0.44 per cent potassium by dry weight when grown without potassium in the solution, and 2.69 per cent when this element was included. Other kinds of fruit trees showed the same relationship.

The potassium content of leaf samples obtained from trees growing under various systems of culture and different degrees of potash fertilization, analyzed by this method, are given in Table 14.

TABLE 14. POTASSIUM CONTENT OF LEAVES ANALYZED BY THE SPECTROGRAPHIC METHOD

(*After Wander*)[59]

Location of Tree from which Leaf Samples Were Taken:	*Potassium Per Cent of Dry Weight*
Tree 5/2, Orchard J, Wooster (NPK plot)	1.42
Tree 13/14, Orchard J, Wooster (NK plot)	1.50
Cultivated tree, Orchard C, Wooster	1.26
Mulched tree, Orchard C, Wooster	1.38
Tree 197, Orchard A, Wooster (heavy mulch)	1.90
Tree 325, Orchard A, Wooster (heavy mulch)	1.67
Deficient tree, Canada	0.40
Moderately deficient tree, Canada	0.80
Nondeficient tree, Canada	0.85
Deficient tree, Massachusetts	0.35
Nondeficient tree, Massachusetts	1.51
Samples from Sand Culture in Greenhouse:	
Apple — K culture	0.44
Peach — K culture	0.44
Plum — K culture	0.21
Cherry — K culture	0.29
Apple + K culture	2.69
Peach + K culture	2.29
Plum + K culture	3.15
Cherry + K culture	2.29

Based on the potash content of leaves as revealed by the leaf analyses made by various investigators, it may be stated that the soil fertility should not be allowed to drop below the point where from 0.7 to 1.0 per cent of potassium is found in the dried leaf material. This is the minimum amount to be maintained, and undoubtedly better growth and vigor results from a fertility which will result in leaves containing from 1.5 to 2.0 per cent K on a dry weight basis. Apple leaves which contain above 2.5 per cent K are being maintained on a higher level than necessary.

From the lack of agreement on these matters the student should not infer that there is room for different schools of thought. It means that the information is incomplete as well as that different soils require different treatments. Facts with their proper interpretation are needed.

Carriers of potassium. Salts of potassium are usually referred to as "potash" in the fertilizer trade and are rated on the relative amount of potassium they contain as calculated to K_2O. The ones generally used are muriate of potash (KCl) and sulfate of potash (K_2SO_4). Occasionally KNO_3, kainit, K_2CO_3, or K_3PO_4 is used.

Muriate of potash usually contains not less than 48 per cent of potash (K_2O) principally as the chloride. Sulfate of potash carries the same amount of K_2O as the muriate but chiefly as sulfate and not more than 2.5 per cent of chlorine. Kainit, a mineral compound of KCl and $MgSO_4$ containing considerable rock salt (NaCl) varies widely in composition. Commercial kainit contains 12 to 16 per cent K_2O. Potassium carbonate (K_2CO_3) and potassium orthophosphate (K_3PO_4) are not used to any appreciable extent as fertilizers but are used to some extent in the manufacture of special grades of fertilizers for certain crops. Potassium nitrate contains not less than 12 per cent nitrogen and 44 per cent potash. It has usually been assumed, and with some data for support, that the sulfate is superior to the muriate form. Since about half of the muriate is Cl it is not surprising that injury from this salt has been reported. Sulfate was definitely reported as superior to kainit as a manure for raspberries at East Malling (England).[57]

By far the greatest portions of potassium salts used as fertilizer are naturally occurring products that have in most cases been concentrated.

Hardwood ashes were formerly used about fruit trees, but their scarcity at the present time has greatly restricted their use. They vary in their composition, but if unleached will contain from 4 to 6 per cent potash, 1.5 to 2 per cent phosphoric acid, and 25 to 30 per cent of lime.

Animal manures in the orchard. The scarcity of animal manures has long since forced agriculturists in general to look elsewhere for plant nutrients and organic material. From the beginning of the last century manure was the universal fertilizer for all crops, but gradually "chemicals" came into use so that by the time orchard fertilization began extensively (about 1910), other materials than manure were dominating the field.

There has been some controversy and it is still a moot question whether manure is superior for plant growth to chemicals carrying about the same amount of nutrients as is carried in a given quantity of manure. Analyses of manure vary considerably. At the Rothamsted Experiment Station it was estimated that manure carried 12.75 pounds of nitrogen, 2.19 pounds of phosphorus, and 12.44 pounds of potassium per ton. The manure used in Pennsylvania field experiments was computed as carrying the equivalent of 9.8 pounds of nitrogen, 2.82 pounds of phosphorus, and 7.14 pounds of potassium per ton. That manure will lose nitrogen under almost any condition is familiar to all observers in the ammonia odor in stalls or field. A part of this will be carried into the soil by rain. Potassium and other mineral elements are also leached from manure, which accounts in part for the difficulty of assigning a definite value to it.

As indicated under a discussion of "organic matter" in a previous chapter, it is a surprising fact that crops may be grown successfully without the addition of organic matter to the medium. Thorne points out that "when these crops [field crops] have been grown in rotation with clover, the yields have been maintained for 40 years in the Pennsylvania test at least as well by chemicals as by manure, and in all the Ohio tests the chemicals are showing at least equal effectiveness, pound for pound of elements contained, to the chemicals." [53]

There are many who challenge this concept that manure is valuable only for the nutrients which it contains. Plant hormones or growth-promoting substances which it carries are now emphasized. Yet in the orchard it has been slower than inorganic nitrogen in producing effects, and much of the benefits which ultimately accrue from its use have been credited to the mulching effect of conserving moisture. Excessive use of manure also results in coarse fruit of low color.

Time of application. There is a trend to apply quickly available forms of fertilizer somewhat earlier than formerly. If applied the latter part of March or early April in the northern states there is less likelihood that the grass or other orchard cover will compete with the trees for it at that time. Tree roots absorb nitrates early in the season, and there does not seem to be the loss from spring applications through leaching that was earlier anticipated. This is judged by appearance and yield of trees, and from the experimental data of Batjer and Magness.[10]

Fall applications of nitrogen fertilizers have come into vogue in some sections and have long been practiced in others (e.g., the Northwest). Attention was called to fall applications by Hooker who pointed out that the nitrogen content of spurs may be increased by applying this element in the late summer or autumn previous.[33]

Since Hooker's work, much has been done to show that fall applications of nitrogen yield practically as good results as those made in spring, and some writers have considered them superior. It has been shown, for instance, that nitrogen is absorbed by roots in the autumn and held there as a reserve until growth is initiated in spring.

The following data are indicative of those obtained elsewhere and show that even such a quickly soluble form as nitrate of soda has given a yield from fall treatments equal to spring. A small block of Stayman Winesap trees was planted in 1915 at the Ohio Station and treatment began in the fall of 1921. Five trees constituted a plot. The rate of application was ¼ pound per year of age and the trees were kept permanently in a bluegrass sod. (Table 15.)

TABLE 15. AVERAGE ANNUAL YIELD OF STAYMAN WINESAP TREES FROM SPRING AND FALL APPLICATIONS OF NITROGEN, OHIO STATION—1922–1937

Treatment	*Yield* (*lbs.*)
Normal nitrate in spring (¼ lb. per year of age)	234
Normal nitrate in spring (¼ lb. per year of age)	224
Normal nitrate October 1 (¼ lb. per year of age)	215
Normal nitrate October 1 (¼ lb. per year of age)	229
Untreated	146 [a]
Untreated	48

[a] There was probably some extension of the roots of these trees into the adjacent fertilized row.

Recent work, however, indicates that in moderately heavy soils "downward movement of nitrates was sufficiently rapid to indicate that if as much as 15 inches of precipitation occurred during the dormant season following a fall application, much of the nitrate would be below the depth of effective root concentration at the time growth started in the spring." [10] These observations would not seem to be in accord with the tree response secured at the Ohio Station and elsewhere. Further investigation of this matter is desirable.

It should be noted that late summer applications may result in delayed or lack of maturity of tissues with consequent susceptibility to winter injury.

Since nitrate nitrogen leaches readily the question arises whether two or more applications would not be better than one, that is, split applications. This might be part in autumn and part in early spring or else part in early and part in late spring or early summer. The experience of the authors has not warranted this practice although others have secured some improvement by it. It is important that the trees be adequately supplied in spring when nitrates are frequently (but not always) low in the soil, if the most efficient foliage is to be secured. Therefore, a small application at that time may be reflected throughout the season. No improvement in size of fruit seems to result from late summer applications.[43]

Early spring applications of nitrate of soda in a sod orchard has occasionally resulted in such a heavy production of bluegrass that the soil nitrates were exhausted by the grass roots. Such trees failed to make the characteristic response from nitrogen fertilization until the grass was destroyed, partly or entirely, by disking or plowing. When the application was made 3 weeks later, i.e., 3 weeks after the first signs of bud growth, the results to the trees were much more favorable. This is not a common experience and there is a tendency toward early applications, as indicated above.

Rate of application. No arbitrary standard can be set with any degree of accuracy for the rate of application of fertilizers. The amount required varies with the soil, the cultural system followed, age and kind of trees, and other factors. However, there is need for some specified amount as a point of departure and this amount should be varied as experience dictates.

It has become customary to use nitrate of soda at the rate of ¼ pound for each year of a tree's age, thus a 4-year-old tree would receive 1 pound, a 20-year-old tree, 5 pounds. Some such quantity has proved to be applicable to a wide range of conditions, but is purely empirical. Other carriers of nitrogen would be applied in proportion to the percentage composition of nitrogen.

Superphosphate (20 per cent) when needed is applied at the same rate as nitrate of soda. Muriate or sulphate of potash varies in application from none to about 300 pounds per acre, or about ⅔ to ¾ as much as nitrate of soda.

In a 15-year-old apple orchard which received 3¾ pounds of nitrate, 3¾ pounds of superphosphate, and 2¾ pounds muriate of potash, the total application would be 250 pounds actually applied per acre, or if the entire area were treated at the same rate instead of beneath the trees only, it would require 833 pounds. If a ready-mixed complete fertilizer is used as an all-over application, the rate is approximately 800 pounds per acre.

On certain of the soils in Florida it is not uncommon to apply a complete fertilizer three times a year. A "rule of thumb" is to apply 1 pound for each foot of spread of tree at each of three applications. Potash is commonly decreased in spring and increased in the fall, using such formulas as 4-7-5, 3-8-8, and 6-5-3. On some of the Florida soils there is a definite deficiency of such elements as copper, zinc, manganese, and magnesium, and both orange and grapefruit trees respond to applications of them to the soil. Seedless varieties of grapefruit do not show the deficiency nor need repeat applications as quickly as the seeded varieties.[12]

Methods of application. At the present time no satisfactory device is in use to apply fertilizers around the tree. Such a tool would find wide use. When fertilizers are applied to a mulched or sod orchard they are merely broadcast by hand on the mulch or sod, and the succeeding rains dissolve and carry them into the soil. When they are applied over the entire orchard area they are drilled in or on the land, or spread broadcast by some other device.

Factors affecting color of fruit. Color of fruit is affected by various cultural and environmental factors, such as pruning, thinning, cultivation, and fertilization, as mentioned elsewhere. The general subject of color might be treated in connection with one of the above subjects, since it is directly related to leaf functioning, but it is discussed here because of its intimate relation to nitrogen.

In most fruit sections a high development of red color is the limiting factor in the production of the better grades. Likewise, it is difficult to improve. First, the question should be asked, What is color? Of what does it consist? Under what conditions does it develop? Color is familiar to us throughout the plant world. Green is most common, although other colors in flowers, fruits, and leaves are likewise familiar. These colors are due either to small colored bodies within the cells known as plastids (orange, yellow, and green), or to soluble anthocyanin pigments (blue, purple, violet, magenta, and nearly all reds). Some colors such as scarlet, orange-red, brown, and black are due to both agencies. Yellow color is frequently due to carotin/xanthophyll, both constituents of green leaves.

The anthocyanin pigments arise from a product known as chromogen, which in turn depends for its existence on a supply of carbohydrates (sugars) which are the products of the green leaf. Hence, if there is a shortage of reserve carbohydrates in the plant the anthocyanin may fail to develop because of a lack of chromogen. This relationship may be roughly represented by the following formula:

$$CO_2 + H_2O + \text{chlorophyll} + \text{light and temperature} \rightarrow \text{sugars} \rightarrow$$

$$\begin{array}{l}\text{glucosides}\\ \text{chromogen}\end{array} \xrightarrow{\hspace{6em}} \begin{array}{c}\text{anthocyanin pigments}\\ \text{red color}\end{array}$$

This relates the whole problem of color back to the nutritional condition of the tree, together with favorable sunlight and temperature. As long as the nitrates entering the plant combine with practically all the available sugar and form organic nitrogen, there will be no accumulation of carbohydrates from which chromogen is formed. This is the situation in trees making excessive growth and producing fruit of poor color.

Dustman and Duncan [19] have reported on experiments designed to study the effect of certain sprays on the development of red and yellow pigments in the apple. It was shown that the red pigment is a complex organic substance known as idaein, a glycoside which yields cyanidin and galactose on hydrolysis. Soluble thiocyanates, particularly inorganic thiocyanates such as those of sodium, potassium, calcium, and barium, applied as a spray to apple trees during the growing season exerted a pronounced physiological effect on both foliage and fruit. Favorable results were obtained with 2 to 4 sprays of 0.1 per cent concentration of sodium thiocyanate applied during the latter half of August and early September. In the foliage the leaves are subjected to spray burn and to a chlorotic condition arising from the effect of the chemical on the green coloring matter of the plant. In the fruit the amount of red color occurring normally tends to be increased and the green ground-color tends to be replaced by varying shades of yellow and yellow-green. The authors consider the work somewhat preliminary but this work, together with that of Gardner, Marth, and Batjer (page 364), are suggestive of new approaches to the color problem.

Relation of leaf area to color. It would follow then that a tree with insufficient leaf area to properly mature its crop would produce fruit of relatively poor color, since the sugars are produced in the green parts. This situation has been produced experimentally by Magness in the state of Washington.[36] (Table 16.)

An increase in color is developed as the number of leaves per apple increases. Therefore, up to a certain point, the more leaves the higher the color, provided they do not excessively shade the fruit. That excessive crops are poorly colored has frequently been observed.

Fruit is also likely to be lacking in good red color in a season of excessive drought. Sugars may actually accumulate in relatively high percentage under such conditions as well as tannin and astringent substances. Several factors may be involved in the low color which is developed.

TABLE 16. RELATION OF LEAF AREA TO SUGAR CONTENT AND COLOR. DELICIOUS APPLES, WENATCHEE, WASH., 1928

(After Magness)[36]

No. of Leaves per Apple	*Sugar Content, per Cent*			*Solid Red Color Average per Cent of Surface*
	Reducing	*Non-Reducing*	*Total*	
10			10.06	
	9.19	0.45	9.64	23
20	10.23	1.01	11.24	
	8.96	2.12	11.08	26
30	9.96	1.51	11.47	
	9.20	2.44	11.64	42
50	10.11	3.07	13.18	
	9.62	3.60	13.22	51
75	10.84	3.29	14.13	
	9.92	4.86	14.78	58

Light as a factor in color. For many years horticulturists were likely to say that red color was due entirely to the exposure of the fruit to sunlight, and as evidence it was pointed out that shaded fruit was poor in color. There is so much truth in that statement that it is not at all strange that a more thorough analysis was slow in developing. Red color in apples, pears, and peaches requires presence of sunlight on the fruit for there is no increase of it in storage. On the other hand, the strawberry, cherry, blackberry, and grape will develop anthocyanin without the presence of light.[41]

In experiments in which apples were covered with black bags through which no light was transmitted, no red color developed except on Williams Favorite. Furthermore, it has been shown that it is the blue end of the spectrum which is responsible for the development of the red color. Magness detached apples from the tree after they were developed but uncolored and placed some under glass which screens out much of the ultra-violet rays. A sample was also exposed to direct sunlight. The following condensed table shows the great reduction in red color after twelve days when the ultra-violet rays were screened out of the light reaching the apples.[36] (Table 17.)

Magness states that color develops only one-fourth as fast under glass as in direct sunlight. In this connection it should be remembered that much of the ultra-violet rays are screened out of the light at low altitudes by dust, smoke, and other particles. At high altitudes this is not true, and the colors of flowers and fruits are known to be much higher under such conditions.

TABLE 17. COLOR DEVELOPMENT OF DETACHED APPLES UNDER GLASS AND IN DIRECT SUNLIGHT

(After Magness) [36]

Variety	*Percentage of Solid Red Color*					
	When Started		*After 5 Days*		*After 12 Days*	
	Under Glass	*Full Sunlight*	*Under Glass*	*Full Sunlight*	*Under Glass*	*Full Sunlight*
Jonathan	6.8	8.6	10.5	37.7	44.0	96.0
Delicious	4.5	5.4	5.6	24.2	17.3	74.0
Rome Beauty	2.5	2.0	4.0	8.0	9.3	36.3

Therefore, light is an indispensable factor in the development of color pigments in the apple, but only after there is a development and accumulation of certain sugar derivatives.

Temperature. It has long been noticed that red pigment develops in fruits (and often in foliage) following periods of low temperature. Consequently, it is not surprising to note that fruits (notably the apple) develop a higher red color in an autumn when there are periods of relatively low temperature during the ripening season. The other factors already described are also operative and may reduce or enhance the effect of low temperature.

Bud sports. The best assurance of securing better color of apples is to plant the red bud sports of the red varieties of apples. Many of them have been found and are on the market. However, no blanket endorsement can be given to red strains; each one must be thoroughly tested for characteristics other than color before it can be accepted.

Fertilization Practice

Aside from theoretical considerations and general principles of plant growth, the student of pomology should examine evidence from the orchard. The results from a large number of experiments may be examined to learn whether there is any general trend in response to one or more elements. That results will vary on different soils, with different fruits, and under different conditions, and that there will be exceptions to general trends, would be anticipated. But the student, like the orchardist, should never have a closed mind but be open to new evidence whenever it is found. As pointed out earlier, there is no one answer to the fertilizer question.

Tilled and nontilled orchards. The source of much difference of opinion in earlier times lay in the failure to recognize that tilled and nontilled orchards frequently respond differently or at a different rate to treatment. A tilled orchard, especially when legumes are used as a cover crop, frequently is well supplied with nitrates as contrasted with a sod orchard. Not infrequently cultivated apple orchards have not given clear-cut responses from any kind of fertilization even over long periods of time. This is not always true, however, since orchards on land of low fertility such as may be found in sections of southern Ohio gave as great and as prompt returns from nitrogen in tilled as in sod orchards.[6] This is not the usual experience, and the authors would emphasize the importance of knowing the system of culture as well as the nature of the soil in drawing conclusions from any fertilizer experiments.

So striking are the differences in response of different kinds of fruit to cultural and fertilizer treatments that certain groups of fruits will be studied separately.

Fertilizer practices with the apple. Experiments in the fertilization of this fruit are so extensive that a complete record cannot be attempted. Some were conducted on soils or topography that were so ununiform that conclusions from them are worthless. Other reports are more of a philosophical character or what may be termed "guessing" than based on sound data. Exactly uniform conditions of all factors are almost never present, and hence general trends must be examined. Results from pot cultures when conditions are controlled can be interpreted in terms of field conditions only with the greatest caution. (This has made fertilizer experiments most difficult to conduct and interpret.) Some conclusions from field work, however, seem warranted and a few of the data may be examined. As stated elsewhere, the response of apple orchards to fertilizers depends upon the soil, age of trees, whether the orchard is cultivated or in sod, and other factors. Cultivated orchards frequently are slow in showing a response and may never give a profitable return from the chemicals applied. Occasional tests give the most reliable answers.

Typical of the early results in fertilizing mature orchards which had become unproductive is the work in Ohio.[6] The orchards selected were in Washington County (southeastern Ohio) on land low in native fertility, and where the surface soil was very thin, usually supporting a cover of poverty-grass (*Danthonia spicata*) and weeds. The land erodes badly and hence it was not deemed wise to cultivate it. The supposition was in these initial experiments that potash would give best results although superphosphate had proven best with some agronomic crops. Nitrogen was considered objectionable. However, the plots were laid out so that each element (N,P,K) was used separately and in various combinations. Also manure was used in one plot and one row of trees was left untreated as a check. Within a few weeks certain rows stood out from the others and could be recognized from adjacent hills a couple of miles away, to the surprise of both the investigators and the neighborhood folk.

The element which gave immediate results was nitrogen, whether used alone or in combination with other elements made no difference. The beneficial effects continued each year, and demonstrated beyond question that the first and most important need for these orchards was a quickly available form of nitrogen. The nitrogen used at that time was in nitrate of soda and manure. When phosphoric acid was used in combination with nitrate of soda or in a complete fertilizer, there was little or no evidence that it was a limiting factor, although the soil was low in phosphorus. However, it proved of great value in securing a stand of better ground covers, especially clover. Neither did potassium have any apparent effect in increasing the vigor or yield of the trees nor appearance of the fruit during the 5-year test.

Much the same type of work was carried on in Massachusetts, Pennsylvania, and New York, during that period. The Massachusetts work showed important gains from potassium, wood ashes, and manure, but it was later pointed out that the check or untreated plot with which the above treatments were compared, was in an unfavorable place, and that probably the only significant gain was from barnyard manure.

In the Pennsylvania experiments the striking effect at first was from nitrate of soda and manure. Later Stewart reported that "The addition of phosphorus or potassium to nitrogen applications had usually given larger returns than nitrogen alone. . . . In at least three of the other bearing orchards, however, the addition of phosphorus has resulted in no important benefit." Also "Potash has increased the yield materially in three of the experiments in bearing orchards and apparently has shown some value in increasing the size of the fruit. It has also apparently had an injurious effect in two of the eight experiments. It would seem advisable, therefore, to defer its general use in any particular orchard until definite evidence of its value is secured." [50]

After 25 years' work in one cultivated orchard Fagan, *et al.* report that "In this orchard, any treatment that has influenced the trees at all has done so in the following order: First, the cover crops; perhaps several years later, leaf color; shortly after, branch growth and circumference increase; and last of all, yield." [21]

The earlier New York work showed little or no response from any kind of fertilization. The experiments were carried on mainly in cultivated orchards, however. After 20 years' work the conclusions were drawn that, "In general there are so many inconclusive or contradictory results that no conclusion of practical value can be drawn from the yields. Heavy applications of nitrogen in a complete fertilizer and in manure have not increased tree growth. When the costs are considered, certain plots have given increases sufficient to equal costs, or even to show a profit, but in other plots the same plant food elements have shown a financial loss." [28]

From a number of experiments subsequently carried out with the apple in New York on various soil types and in different geographical regions, the following general conclusions may be drawn. The chief element to which orchards respond is nitrogen. Several others are equally important but appear to be present in sufficient amounts as to require no additional amendments to the soil.

It is recognized that nitrogen should be available at the time growth starts in sufficient quantity to provide for the needs of the tree and to influence the set of fruit. In a sod orchard where the tree competes with the grass or other cover, an application in a quickly available form is often needed in early spring. Since the nitrogen of the soil is derived largely from the organic matter, it is important to maintain an increasing ratio of it rather than to allow it to disappear by intensive tillage.

From the standpoint of other elements a number of investigators have concluded that there is very little evidence that a complete fertilizer containing nitrogen, phosphorus, and potash has given any increased yields over the use of nitrogen alone. This covers several soil types in western New York and several varieties of apples. In the Hudson Valley similar results were recorded. All trees receiving phosphorus and potassium also received nitrogen and yet neither of the former two nutrients gave any significant yield increase or girth gain over nitrogen alone, and this is in a light soil of rather low productivity. The yield responses of eight different nitrogen carriers were about equally significant, while lime had no apparent effect.[13]

Much the same results were secured in West Virginia,[1] in Arkansas,[52] and elsewhere. In the state of Washington results were not obtained from any other element than nitrogen. In fact, both phosphorus and potassium appeared to depress yield and growth.[40]

Davis and Browne recommend for high lime soils in Quebec that 1 pound of superphosphate and 2 pounds of muriate of potash be applied to a tree with a trunk diameter of 6 inches. Nitrogen should be applied as the color of the foliage and terminal growth indicate. Where mulch is used, much less nitrogen will be needed than otherwise. For low lime soils, they recommend a 9-5-7 fertilizer at the rate of 1 pound per inch of trunk diameter where mulch is not used and a 4-8-10 where large amounts of mulch are used.[17] When corky core, or similar troubles have occurred, it is recommended that borax or boric acid, at the rate of 2½ pounds per 100 gallons, be used in the calyx and either first or second cover sprays. Or in lieu of this treatment, from ¼ to 1 pound of borax may be applied beneath the tree provided there has been no application within 3 years.

Fertilization of stone fruits. It has been seen that cultivated apple orchards are frequently slow in showing any response to fertilization when they are grown on moderately fertile soil, but this is not true of the peach and apricot and usually not true of other stone fruits. The peach in particular responds readily to both cultivation and nitrogen treatments and is prompt in showing the effects of neglect. Moisture as well as nutrients may be the limiting factor in the production of stone fruits (as well as apples) and this factor should not be neglected.

Results in West Virginia covering a period of 13 years, showed that nitrogen was the only element which increased growth or yield, and neither phosphorus nor potassium was recommended. Lime gave some suggestion of improvement in one plot and negative results in another, and it was recommended only for the cover crops. One hundred and fifty pounds of stable manure per tree had the same effect on growth and yield as 4 to 6 pounds of nitrate of soda. Color of peaches is readily reduced and the time of ripening delayed by the application of excessive amounts of nitrogen, whatever its source. Flower buds were not found in greater abundance under fertilization, but the larger tree gave increased yield as a result.[14]

In the early period of the work investigations in Arkansas failed to show a response on peaches from any nutrient except nitrogen. In later years, however, a complete fertilizer gave better results. It was recommended to use 50 pounds of P_2O_5 and 25 pounds of K_2O per acre in the fall and 25 pounds of nitrogen in the spring. As the trees reach 10 years of age, 5 pounds of nitrate of soda per tree is advised.

The sour cherry may produce fair crops for a period of time without fertilization, but on many soils a distinct improvement in yield can be expected when nitrogen is applied. In Wisconsin, Early Richmond trees increased in production when nitrogen fertilizer was used alone or in combination with phosphoric acid and potash, but there was no gain from the latter two when used by themselves.[46] Furthermore, Roberts showed that the yield is influenced definitely in that section due to winter killing of flower buds. Richmond trees that received no fertilizer had 64 per cent of the blossom buds killed by cold in contrast to pruned and nitrated trees where 19.5 per cent were killed and to young trees where 10.0 per cent only suffered. He also noted that trees receiving nitrogen produced more of the crop on 2- and 3-year-old spurs, while trees receiving no nitrogen produced their fruit largely from lateral buds on 1-year-old wood, thus precluding the possibility of spur formation. Both Early Richmond and Montmorency produced more leaf buds as the shoots increased in length. This resulted in a larger bearing surface and hence higher yields.[45]

Equally favorable results were obtained by Gardner in Michigan.[22] The bearing surface of the trees was greatly increased from nitrogen, but no such results were obtained from other materials. This is graphically expressed when it is reported that "10 cents' worth of fertilizer per tree led to an increase in production of 15 pounds, worth about 75 cents on the tree." In later years this was increased to $1.30 and $2.90 respectively. Not only was growth and yield increased by the use of 2½ pounds of sulfate of ammonia per tree, but leaf size was increased from 25 to 35 per cent.

In California it has been determined from 10 years of experimental work with peaches, prunes, pears, apricots, and almonds that deciduous fruits were not found to respond profitably to potassium or phosphate. A response to nitrogen, though common, was not always obtained.[44]

The grape. As with most other fruits, fertilizer experiments with the grape have given variable results. The nature of the soil, drainage conditions, presence or absence of destructive insects and diseases all play such a large part in the behavior of the grape that the effects of fertilizer treatments may be masked by them.

In a summary of 25 years' work with the fertilization of Concord grapes in New York, it was shown that increased yields resulted from a complete fertilizer (N,P,K) but most of the results are from nitrogen and potassium. But the check plot with which the treated ones were compared was unfavorably located, and the results lack the significance they would otherwise have had.[23]

Beneficial results were obtained in Michigan from the use of nitrogen, and somewhat less results from potassium and phosphorus. The increased yields were largely obtained as a result of the greater growth of the vines.[42]

On two soil types in Ohio the only outstanding results were obtained from animal manures. In some seasons there appeared some response from chemical fertilizers, but the yields were erratic and no definite recommendations could be made from them. But in all cases and every year, the manured plots were superior. On another lighter soil type a reasonable response was secured from inorganic nitrogen, which would indicate that the sandy types of soil are likely to respond to this element.

At Vineland, Ontario, an experiment was conducted on the typical grape soil of that region, Vineland clay loam, for a period of 8 years, 1929–36. Plots were carefully laid out, replicated, and checked. "The soil was very low in readily available phosphorus, low to medium in replaceable potassium, fairly high in replaceable calcium, but medium acid in reaction and medium in organic matter.

"Nitrate of soda alone was ineffective in increasing growth or fruitfulness and, in fact, there was a slight depression of growth and fruiting. The increases in yield from the various fertilizer combinations were very small, the combination of nitrate, phosphate, and potash giving the greatest response.

"Additions of organic materials, straw, and green manure crops, without phosphate and potash have given marked increases in growth and fruit production." [55]

On light soils, or where organic matter is low in a soil it is advisable to use ⅓ to ⅔ pound of nitrate of soda or its equivalent per vine. It is usually broadcast over the entire area.

Small fruits. It is highly important that land for small fruits be well drained. A favorable site and soil are more important than any fertilizer formula. However, it is quite customary to inquire for the best formula for the berry fruits. A survey of the literature reveals little positive information such as can be found in abundance for the tree fruits. It is much more important, for instance, to plant strawberries early on suitable and well-prepared soil than to select a fertilizer for them. It is customary to recommend 200 to 300 pounds of a nitrogen fertilizer per acre. On sandy or less favorable soils 400 to 500 pounds of a 10-20-10 or double the amount of a 5-10-5 mixture has been suggested. The use of animal manures is usually beneficial. Wallace and Hoblyn obtained beneficial results with all kinds of small fruits when potassium was used. In some cases they also responded to nitrogen.[31, 56, 57]

Relation of Fertilizers to Keeping Quality of Fruit

One of the conspicuous effects of quickly available nitrogen fertilizers is to stimulate vegetative activity and to some extent induce succulence in plants. This fact has given rise to the concept in some quarters that fruit trees treated with nitrogen alone will produce fruit that keeps poorly and hence should be avoided.

It is well known, for instance, that most fruits develop less red color if excessive amounts of nitrogen are present, regardless of its source, and hence scald in storage and are more subject to physiological disturbances than when no such excess obtains.

"It was found at New Brunswick, New Jersey, that when peach trees were so actively vegetative as to be classed as high-nitrogen in growth status, the flesh of the fruits was more tender throughout the season, and lower in sugar and edible qualities at maturity, than that of fruits produced upon trees in a high-carbohydrate condition. . . . The unqualified statement that nitrogen makes peach fruits soft is incorrect. It may or may not. The firmness of the flesh is intimately associated with the growth response of the tree, that is, whether it is actively or weakly vegetative.

"An application of nitrogen which brings about a change from a high-carbohydrate to a medium-high-carbohydrate growth status in a peach tree is desirable in every way. The flesh firmness of the fruits is not reduced to any extent, and the edible qualities are maintained. Since the yield and average size of the fruits "are almost certain to be increased, it is sound orchard practice."[11]

It is further pointed out that the difficulty is with the improper use of fertilizer rather than with the nitrogen itself.

In a fertilizer experiment with peaches in West Virginia it was observed that nitrogen-treated trees ripened their fruit from 2 to 10 days later than those without it. But, it is pointed out that the greener peaches should not be ascribed directly to nitrogen in view of the reduced sunlight which reaches the peaches as a result of the dense foliage.[14]

It has been shown that the application of nitrogen to apple trees, both in sod and cultivation, resulted in an increase in the percentage of total nitrogen in the fruit and also in an increase in the total amount of nitrogen per apple. While scald was increased as a result of the decrease of coloration, there was no increase in amount of decay or physiological breakdown. No amount of nitrogen (up to 5 times the normal) induced breakdown of the fruit. Any factors which increased size of fruit resulted in poorer keeping quality.[24] In years of light crops the fruit was larger and usually broke down much sooner than in years of large crops, regardless of the fertilizer treatment employed. There was a tendency in these experiments for apples (and peaches) from unfertilized trees to have reduced keeping quality, and a complete fertilizer was not superior in this regard to nitrogen alone.

Haynes and Archbold obtained opposite results in England, as they concluded that apples high in nitrogen had a shorter life than those low in this element.[27]

Aldrich,[2] Magness and Overley,[37] and Degman [15, 16] found no differences in the keeping quality of apples from untreated check and from nitrate- or potash-treated trees. Weinberger [61] reported that "under various soils and climatic conditions in Maryland the use of potassium fertilizers, whether alone, in combination with nitrogen or with nitrogen and phosphorus, has not affected the firmness or keeping quality of apples, peaches, or strawberries."

Other investigations may be cited, some of which indicate that a complete fertilizer, particularly potassium, favors the firmness and keeping of fruit and others are negative. It is apparent that a fertilizer treatment alone is not a guarantee of better storage quality on most soils in the United States. If this were true, most of the fruit produced would keep poorly for, as yet, most orchards receive nitrogen only, and no general objection can be raised in this regard. Nitrogen may lessen keeping quality under certain conditions, just as does injudicious pruning, cultivation, thinning, and other practices. The weight of evidence, in the main, is against the discontinuance of the nitrogen program for that reason.

Summary

In last analysis, no arbitrary or dogmatic formula can ever be laid down regarding orchard fertilization. A knowledge of the soil, of tree condition, foliage color, and optimum behavior as to yield, must be acquired by the grower who can then adjust his practice accordingly.

Fertilizers may or may not give a profitable return in orchards, depending upon the soil, kind and variety of fruit, age of tree, and various factors of the environment.

Nitrogen and moisture are limiting in more orchard soils than any other factors. In some places nitrogen may be present or supplied in excess and should be reduced if favorable color of fruit is to be obtained and unbalanced nutritional conditions of the tree avoided.

Where needed, the nitrogen should be applied beneath the outer portion of the branches in spring or fall. The rate is approximately ¼ pound per year of age of the tree. This amount is to be increased or reduced according to the appearance and behavior of the tree. In addition nitrogen alone, or preferably a complete fertilizer, should be applied between the rows of trees at the approximate rate of 250 to 400 pounds per acre, of a 4-10-6, 10-6-4, or 4-8-6 every year or two, as needed for the intercrop.

Potassium is the chief limiting element of fertility in a few places. It should be supplied at the approximate rate of 300 pounds per acre, applied beneath the trees, and worked into the soil when possible. The areas where this element is needed are increasing. In general, it may be stated that the Atlantic Coastal Plain, including a strip 100 or more miles wide from Florida to Maine, is a section that has been heavily leached and apparently is lower in many of the elements of soil fertility than most other parts of the United States. Throughout this area, for example, peach trees quite generally show definite response to potash applications. Strawberries are almost always given a complete fertilizer. This very heavily leached area probably requires in general a different fertilizer program from most other parts of the United States. Failure to recognize this situation may have been responsible for part of the confusion in the literature relative to fertilizer responses in orchards.

Phosphorus and calcium are less often needed.

Fall applications of nitrogen are about equal to spring ones.

The various carriers of quickly available forms of nitrogen give about equal results.

From the standpoint of cover or intercrops the value of a complete fertilizer and lime is recognized in most sections.

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8

WATER RELATIONS OF FRUIT PLANTS

As fruit production has become increasingly competitive during recent years, growers have paid increased attention to the various factors affecting the growth and production of the plant. Since water supply is one of the major factors involved, each phase of the problem has aroused new interest. Furthermore, prolonged droughts, which at times have produced serious consequences have focused attention on the problem of irrigating tree fruits, while it is well known that water deficiency during the fruiting of the strawberry and other small fruits is particularly disastrous.

The attempt to meet the problem of adequate water for fruit plants has been approached from various angles. In the West irrigation is the commonly accepted practice; in the Eastern United States irrigation systems have been installed and favorable results reported. In other cases, there has been an attempt to conserve, rather than to introduce water, and in such cases mulching has been found to be outstandingly effective. At the same time investigation has emphasized the importance of deep rooting, and of effective methods of securing soil aeration, as an indirect means of providing an adequate water supply. In view of added interest and consequently of added knowledge, growers are attempting to apply available information to their specific requirements in such a way as to make future drought periods less hazardous.

This chapter will discuss the major aspects of water supply in relation to fruit plants, taking into consideration the experimental work which has been conducted upon such plants. Particular attention is given to irrigation as a means of control of available water.

RELATION OF WATER SUPPLY TO GROWTH AND FRUITING

Functions of water. The predominant physiological processes of the plant, such as photosynthesis and the synthesis of organic nitrogenous compounds from inorganic nitrogen and carbohydrates, are dependent upon an available water supply. When the cells of the plant in which these processes occur have a *maximum* water content (are turgescent) the rate of formation of these substances is at a maximum. On the other hand, as the moisture content of the cells is reduced, the rate decreases more or less in proportion to the reduction in moisture. Finally, when the loss in turgidity has become sufficient to be perceptible, wilting is observed. However, it should be kept in mind that before wilting is evident, the rate at which the various processes occur has usually been definitely retarded. For example, the rate of photosynthesis decreases with a reduction in moisture content, but, from available evidence, it is only when the leaves wilt that the process is all but interrupted.[19]

A maximum rate of cell division also depends upon the complete turgidity of the cells concerned. Although a maximum rate is not *constantly* essential, nevertheless, growth, of which cell division is the first step, is definitely retarded whenever turgidity is decreased.

Cell enlargement, the second phase of growth, is also greatly retarded by water deficiency despite the presence in the tissues of an adequate supply of inorganic nitrogen. It must be emphasized that the retarding effect is not necessarily due to the fact that water is insufficient to dissolve the nitrogen-carrying salts applied to the soil. Recent evidence also indicates that water deficiency reduces the stability and increases the mobility of various organic nitrogenous compounds. Thus proteins are hydrolyzed to amino acids;[36, 38] which are subsequently translocated from the older to the younger leaves.[36] As a consequence many of the older leaves become yellow and eventually abscise, a result easily produced in water-deficient tomato plants. Evidence also indicates that the activity of enzymes is affected by water deficiency. The enzymatic hydrolysis of starch with consequent increase of sugars is an example of this.[26]

Symptoms of water deficiency. One of the first symptoms of water deficiency is a reduction in the rate of plant growth, and of fruit growth in particular. This symptom may develop considerably in advance of others. In locations where the rooting is shallow, and the roots are compelled to compete with the roots of blue grass or alfalfa, the younger foliage of the trees may present a dark green, healthy appearance but at the same time the rate of growth of trunk and stem is retarded and the shoots are abnormally short.[24]

Wilting is obviously unmistakable evidence of water deficiency, but wilting of fruit trees, even in drought seasons, is not an inevitable indication. Frequently in fruit trees some leaf abscission may occur previous to wilting.

An additional symptom of water deficiency is an accumulation of carbohydrate materials resulting in the thickening of the cell walls. Furthermore, the stems tend to become less succulent and more woody and to remain rather slender in diameter due to the retardation of cambial growth.

Finally under extreme deficiency the tissues or organs of the plant may die, or isolated portions may show a breakdown resulting from desiccation. This desiccation develops rather readily in the older leaves of plants suffering from potassium deficiency, in which case it is called "leaf scorch." The water content of fruits may be considerably reduced by deficits set up in the leaves. During periods of considerable stress due to excessive transpiration, water is withdrawn from the fruits of deciduous plants by the leaves, resulting in a slight decrease in volume [8, 16] On the other hand, in the lemon considerable change in volume occurs. These periods of water deficit in the fruits may be intermittent, or persistent, depending upon prevailing weather conditions as well as upon soil moisture. If the temperature is high and humidity low a flaccid condition may develop in the daytime despite abundant soil moisture, but recovery to the original volume will occur during the night. If under such conditions favoring high transpiration the soil moisture is low, recovery may take place at a later hour each night until finally, the original volume and moisture content is not regained by morning.[16] The fruit may then wilt with extreme shriveling developing later. These water deficits even though temporary will, if continued over a period of several days, result in smaller fruits at maturity.

Percentage of water in fruit plants. A considerable proportion of the fresh weight of the various organs of the fruit plant is represented by the water content, which, while it may amount to as much as 90 per cent of the weight of the fruit itself, is considerably less in the roots, stems, and leaves.

Furthermore, the percentage of water in the fruit is known to respond readily to soil moisture and other environmental conditions.[28] Under irrigation the moisture content of the fruits of various tree and small fruit plants varies considerably. For example, the water content of mature apple fruits varies from 82 to 88 per cent of their fresh weight.[28] The strawberry is apparently most sensitive to this factor.[11] Darrow and Waldo report that the moisture content of this fruit ranges from 75 to 95 per cent in response to extremes of dry and wet soil. Thus in irrigated plots where moisture is maintained at a high point, the fruits are inclined to be larger and soft, necessitating careful handling in consequence.[11, 30]

Factors Affecting the Water Supply within the Fruit Plant

This chapter is primarily concerned with the water supply within the fruit plant itself. Brief consideration will be given, however, to aspects influencing either the amount of moisture in the soil or the rate of its entrance into the plant.

In the first place, factors such as texture and structure of the soil affect not only the amount of water available, but also the growth and development of absorbing roots, as discussed in Chapter 5. Secondly, the water supply depends upon the extent and spread of these absorbing roots, and finally upon the environmental factors, such as those governing transpiration, to which the aboveground portions are subjected.

A water deficit may occur within the plant whenever any one of these three groups of factors is unfavorable. For example, with low soil moisture, a water deficit may exist, despite rather extensive root development and environmental conditions favoring only a moderate loss of water by transpiration. Again, a considerable moisture deficit may occur when only the rooting factor is unfavorable. Finally, if the environmental conditions are conducive to a rapid rate of water loss, deficits may occur despite rather extensive root development, and an excellent supply of moisture in the soil. Such a condition is frequently observed during a period of high temperature and low humidity in the growing season.

Soil factors affecting the moisture supply of the plant. The more important soil factors influencing moisture within the plant are texture and structure; organic matter; aeration; position of the water table; temperature of the soil; and concentration of the soil solution. These factors affect one or all of the following:

1. Amount of moisture in the rooting zone.
2. Root penetration and development.
3. Capacity of the roots to absorb water or its rate of entrance.

Only the effect of texture and structure is considered at this point since the remaining factors are discussed in other parts of the text.

Texture and structure. The physical properties of the soil, including texture and structure, determine to a large extent the growth and functioning of the root system. This is primarily due to their effect upon the moisture-holding capacity of the soil, water available to the plant, the drainage, aeration, and permeability of the soil.

The importance of texture in governing the water-holding capacity of a soil is indicated by the greater amount of water retained by a clay loam as compared with a sand. The moisture-holding capacity of 6 soils of the Vernon series in the United States, as indicated by the moisture equivalent, is as follows:[29]

(In percentage of the oven-dry weight)

Sand	3.6	Fine sandy loam	12.3
Fine sand	4.3	Silt loam	19.8
Sandy loam	10.3	Clay loam	23.1

This difference in water-holding capacity is largely a result of the difference in size of particles with a consequent decrease in size of the pore spaces as the particles become smaller. Data at present available indicate that in heavy soils only the water held in the spaces between granules is available for plants. In this connection, Stephenson and Schuster [44] state "whatever their form, noncapillary pores supply the principal means for water penetration, drainage, aeration, and root growth."

The aggregation of clay particles into larger units is believed to be the primary means of overcoming the unfavorable effects of heavy textures. This aggregation of clay particles by increasing size of the pores causes them to function in a manner more similar to sand. Organic matter, roots, and insects are particularly useful in breaking up the soil into the irregular structure necessary for sufficient aeration. Cultivation at the wrong time or use of heavy implements in the orchard may have decidedly unfavorable effects. In the absence of vegetation natural processes such as periodic shrinking and swelling induced by alternate wetting and drying, freezing and thawing, also tend in the direction of improving soil structure.

Soil constants concerned with water-holding capacity. Several constants concerned with moisture-holding capacity of the soil are important to a study of water relations. These are the *moisture equivalent*, *field capacity*, *permanent wilting percentage* (wilting percentage, wilting coefficient, wilting point) and *available water.* The *moisture equivalent* is the best single index for comparing the relative capacity of soils to hold water.[48] It is determined in the laboratory by centrifuging a soil in cups with perforated bottoms against a force of 1,000 to 2,000 times gravity. The amount of water remaining is calculated on the oven-dry basis.

Field capacity, as indicated, is determined in the field and represents the amount of water retained against the force of gravity, following the addition of a superabundance of water to the soil. This constant also, is expressed on the basis of the oven-dry weight of the soil. In soils of fine texture (not of fine sands but of loams) the field capacity and moisture equivalent are found to be nearly the same. For example, the moisture equivalent of the first foot of the Wooster silt loam soil is 22.4 per cent while the field capacity is 23 per cent. The determination of the soil moisture on an oven-dry basis involves drying a known weight of soil (in soil laboratories in an oven at 105° C. or 221° F. over night) until all moisture has been removed. The weight of the dry soil is then determined and its loss, the weight of water, is expressed in percentage of the dry weight of the soil. For example, 123 grams of moist soil, losing 23 grams of water, when dried would have 23 per cent of water on the oven-dry basis.

The moisture equivalent and the field capacity, show the water-retaining capacity of soils of different structure and texture, but these constants do not indicate the amount available for plant growth, although, as a rule, the amount available increases with increase in the moisture equivalent. A clay loam with a moisture equivalent (M.E.) of 25 per cent has a greater amount of water available for plant growth than a fine sand with a moisture equivalent of 5.0 per cent. (Table 18.)

The roots of plants in a soil whose moisture content is at field capacity can absorb water readily, even against the tension force with which the water is held by the soil. (The exception is found in certain very fine tropical clays in which the field capacity is 60 to 70 per cent and the wilting percentage nearly as high.)[44] Gradually absorption reduces the water content to the point at which water is no longer absorbed at a rate sufficient to maintain the turgidity of the plants above the wilting stage. The amount of water remaining in the soil (on the oven-dry basis) when the plant wilts and will not recover until more water is added, is called the

TABLE 18. RELATION BETWEEN THE APPARENT SPECIFIC GRAVITY, MOISTURE EQUIVALENT, WILTING PERCENTAGE, AND AVAILABLE WATER-HOLDING CAPACITY OF VARIOUS SOIL TYPES

Soil Type	*Moisture Equivalent*	*Wilting Percentage* (1)	*Water Available*	*Available Water in Acre Inches per Acre Foot* (2)
	Per Cent	*Per Cent*	*Per Cent*	
Fine sand	5.0	2.7	2.3	0.41
Sandy loam	10.0	5.4	4.6	0.78
Fine sandy loam	15.0	8.1	6.9	1.10
Loam	20.0	10.8	9.2	1.38
Silt loam	21.0	11.5	9.5	1.33
Clay loam	25.0	13.5	11.5	1.61
Clay	32.0	17.3	14.7	1.91
Very fine clay	36.0	19.5	16.5	2.06

(1) Secured by formula, wilting percentage $= \frac{\text{M.E.}}{1.84}$

(2) Secured by use of equation $d = \frac{P'w \; As \; D}{100}$ from Israelsen[27] (page 168).

P′w = the average moisture per cent on the dry weight basis that can be stored, i.e., the per cent capillary capacity (moisture equivalent) minus the moisture per cent before irrigation.
As = the apparent specific gravity of the soil, i.e., the ratio of the weights of 1 cubic foot of dry soil to 62.4 which is the weight of a cubic foot of water.
d = the depth of the water to be applied in feet (or inches).
D = depth of the soil to be moistened in feet (or inches).

*permanent wilting percentage.** At this point, the plant has undergone a reduction in moisture content sufficient to result in continuous wilting day and night.

This constant was shown to have biological significance by the work of Briggs and Shantz[6] who termed it the *wilting coefficient.* In their experiments the wilting coefficient proved to be very similar in any one soil, regardless of the plant involved, but it varied in accordance with soil type, increasing with increasingly fine texture. These results are illustrated below in the wilting percentages taken from data by Keen.[29]

Wilting percentage of various soils secured by use of Kubanka wheat

(In percentage of the oven-dry weight)

Fine sand	2.6
Fine sandy loam	9.7
Clay loam (heavy)	16.3

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* "Permanent wilting" as opposed to "wilting percentage" may convey an erroneous impression. The reduction in moisture content of the tissue is only relatively permanent. Recovery still takes place if water is added to the soil. Objections have been raised to the use of the term "permanent" on this account.

In the Briggs and Shantz experiments the wilting percentage was found to bear a definite relation to the moisture equivalent. The moisture equivalent of the different soils divided by their respective wilting percentages gave the value 1.84, a fact which gave rise to the following formula for determining the wilting percentage without the use of test plants:

$$\frac{\text{Moisture equivalent}}{1.84} = \text{wilting percentage}$$

Since the work of Briggs and Shantz (1912) there are indications that the wilting percentage of a plant in a given soil is somewhat variable, depending upon the environmental conditions to which the plants are subjected during the process of absorption.[7,43] It is not improbable that the condition of growth and the succulence of the plants at the time of test may be factors. However, due to the fact that the variation is presumably small and not of great significance, the wilting percentage is considered to be satisfactory. Within recent years, a standardized direct procedure has been developed as a means of determining the wilting percentage.[52] Instead of utilizing the value 1.84, test plants (usually dwarf sunflower) are grown in the particular soil in which the wilting percentage is to be determined. This method is preferable since Veihmeyer and Hendrickson [46] have shown that in fourteen soils, the division of the moisture equivalent by the wilting percentage (obtained by the use of test plants), gave values ranging from 1.7 to 3.8 with an average of 2.5, as compared with Briggs and Shantz's average value 1.84.

Recently the term *wilting range* has been considered preferable to wilting percentage since wilting of the entire plant does not occur at one definite moisture content but within a range equivalent to 2 per cent. As determined by Furr and Taylor the wilting range represents the moisture content of the soil through the progressive stages of wilting of the basal leaves to the wilting of the upper leaves of well-established sunflower plants.[16]

The term *available water* is now used to indicate the amount of water in the soil available for plant growth. It is calculated as the difference between the *moisture equivalent* and the *wilting percentage.* Table 18 presents data showing the increase in available water with decrease in the size of soil particles. Clay loam soils, for example, usually have more available water than sandy loams, although some sandy soils have more available water than slightly heavier types. Examination of many soils has shown that the available water ranges from one quarter to three quarters of the amount indicated by the moisture equivalent.[49]

The available water in a given soil type may be roughly expressed in inches of water per acre foot by the use of appropriate numerical values. (See page 215.) Table 18 also shows for different soil types the approximate *available water* (in acre inches).

Depth and extent of root development as affecting moisture supply. The soil in which fruit plants grow may be considered a reservoir of water, to which additions are made by rainfall, and from which water is lost by evaporation from the surface, by drainage, and transpiration from the plant. In the upper 6 to 12 inches there is a considerable loss of water by evaporation, but beyond this depth experiments have shown that loss takes place only through root absorption (except when the water content of the soil is above the field capacity,[3, 47] in which case the excess water percolates to lower levels in response to gravity). In fact, loss of water below the surface foot is so largely due to absorption by the fruit plant that drying of the soil during the growing season may be used as a rough index of the spread and depth of the roots.[50]

The moisture content of the soil is lowered most rapidly in the area of greatest root concentration.[3] When the wilting percentage is reached in this area, water may still be readily absorbed from the soil areas having a higher moisture content. Under low transpiration conditions the tree can still function for a considerable time. With high transpiration the root area which can sustain the tree without undergoing severe stress is relatively less. Since deficits are found to be equalized within the plant,[15] wilting, if it occurs, will be temporary, recovery taking place over night. As a still greater proportion of the soil mass occupied by the roots reaches the permanent wilting percentage, a greater water deficit will be set up within the tree, and finally, despite equalization of the water supply, the deficit may become so great as to show wilting during both day and night. At this point, despite the earlier closing of the stomates, with the consequent conservation of water, the moisture of the leaves is reduced to the point where recovery will not occur except by the addition of water.

Since the soil is a reservoir of water, the greater the depth, vertically and laterally, to which the roots extend, the greater the supply of water available for fruit growth. With the withdrawal of water from a particular area, an additional supply can only be obtained (apart from rainfall or irrigation) by further root penetration into untapped areas. It should be understood that one of the principal sources of water for the growth of fruit plants is that obtained by penetration of the absorbing roots into new and unexhausted areas where water is abundant, since only by this means can continuously favorable water supply be maintained, apart from rainfall or irrigation.

If the soil adjacent to the roots of a plant has very little moisture, due either to evaporation or to absorption by plants, the roots will not penetrate into these dry areas.[21] Moist soil at some distance from the roots is thus unavailable. The rate of movement of water by capillary conductivity is too slow to supply the roots with water for more than a very few inches at the most.[9]

That deep rooting is desirable is readily conceded, but its extreme importance is illustrated by the following example. In New York [4] fruit growth was reduced on trees with roots only 2 feet deep while those on trees rooting 4 feet were unaffected. Analysis of the data indicates that the water in the third and fourth foot was responsible for the maintenance of fruit growth on the deeper-rooting trees. In fact Boynton and Savage have concluded in New York that lack of water in the soil seldom limits the productivity of apple orchards which permit rooting to a 4-foot depth.[5]

Serious difficulty also arose with apple trees rooted to a depth of only 18 inches in the Hancock, Maryland, experiments.[33] Since water is lost by evaporation from the soil to a depth extending up to 12 inches, it can easily be inferred that the water available for trees in such a location would be sufficient for only a very short period of drought. In fact, in such an orchard, irrigation would appear to be essential.

Since extensive root development is fundamental in maintaining an adequate water supply, particular attention should be given to those factors which encourage root growth. The soil factors have already been discussed or enumerated; other environmental factors include those cultural practices and treatments conducive to extensive root development.

Environmental conditions favoring root growth. Investigation indicates that an efficiently functioning leaf surface, and the consequent accumulation of carbohydrates, favors extensive root development.

Data of a quantitative nature were obtained in California showing the effect of bearing in reducing the carbohydrate supply in the roots of the sugar prune.[12] Temperature of the soil is undoubtedly an important factor regulating initiation of root growth in the spring and during the late fall and early winter. The growth seems to be greatly restricted below 45° F. Rogers at the East Malling Station in England also reported an appreciable retardation in root growth, while the moisture content in a sandy loam soil was considerably above the wilting point.[40]

The various orchard practices which contribute to the production of carbohydrates in sufficient reserve to furnish an adequate supply for root growth are important in this connection. Fruit thinning, light rather than excessive pruning, the application of dilute sprays, thorough control of insects and other pests, moderate rather than extreme nitrogen fertilization—all these are indirectly valuable in encouraging satisfactory root growth.

Environmental conditions affecting moisture within the fruit plant. The environmental conditions predominantly important in governing the rate of water loss (transpiration) from plants are air temperature, sunlight, humidity, and wind. Since these are discussed in texts on plant physiology, only those aspects particularly concerned with fruit plants are considered here.

Effect of temperature. High air temperature accompanied by low relative humidity encourages a high rate of transpiration. As a result water deficits frequently occur in the fruit and leaves, even though the soil moisture supply is abundant and the roots are actively absorptive.[16, 18] Such a moisture deficit has been called "incipient drying" or "physiological drought," and when the loss of turgidity is sufficient to be perceptible it is called "incipient wilting." Such a water stress, due to excessive transpiration, frequently appears on clear hot days. It may also occur when the soil moisture is reduced in a considerable proportion of the rooting zone, but when water is still sufficient to permit recovery at night when the transpiration is greatly reduced. Incipient wilting is to be distinguished from "permanent wilting" by the ability of the plant to recover when transpiration is lowered. The deficit in such cases is greater if the organs concerned are succulent and not highly suberized or cutinized. Under these conditions the transpiration is particularly high since water is lost, not only through the stomates, but also through the epidermis (called cuticular transpiration).

It has been suggested that under such conditions the limiting factor may be the ability of the water-conducting tubes or tracheae to function adequately. Water is transported through the sapwood of the trunk, and measurements have shown that the trunk of the apple tree has a cross-sectional area smaller than the sum of the cross-sectional areas of the main branches which arise from it.[14]

Experiments and observation indicate that a plant making rapid growth or possessing a large leaf surface and a relatively small rooting area may frequently undergo considerable water stress during periods of high transpiration.[2, 18] For example, water stress with pear trees developed despite the fact that the soil moisture was high in the Meyer soil series in Oregon.[2] At the same time the maximum and minimum rates of fruit growth were associated with changes in air temperatures; when the air temperature reached 96° F. for a few days, the rate of fruit growth fell to a minimum. In California lemon fruits [16] showed a loss of volume during the late forenoon and early afternoon due to rapid transpiration from the leaves and fruits, even though the soil moisture was high. Recovery of moisture in these organs occurred during the late afternoon and night. In Ohio in July 1936 Stayman Winesap fruits on irrigated trees showed a reduction in rate of growth associated with temperatures remaining above 90° F. for a week.[25]

The rate of transpiration has a marked effect upon the rate of water withdrawal from the soil. With rapid transpiration there is an accelerated rate of water absorption as long as it is readily available. This observation is verified by the moisture meter installed in a strawberry plantation.[39] With low temperature and high humidity (reduced transpiration) the rate is so much retarded that the plant may continue to function for some time despite low soil moisture conditions. With high temperature accompanying rapid transpiration and accelerated rate of water absorption, the amount of rooting necessary to prevent water stress in the plant is greater than if the temperature is low and the transpiration much reduced.

Effect of sunlight, humidity, and wind upon transpiration. Sunlight not only increases the temperature thus affecting transpiration, but has an effect upon loss of water by inducing the opening of stomates. With a decrease in relative humidity, an increase in transpiration occurs also. Increased air movement, at least at the lower velocities, increases transpiration both during the day and night.

Water Requisite for Optimum Growth and Fruiting

One of the major problems in connection with the water relations of fruit plants is a determination of the minimum amount of water which will permit optimum growth and fruiting. The idea is apparently prevalent among orchardists that a high moisture content of the soil, close possibly to the field capacity, must be continuously maintained. This assumption is possibly based on an observation of herbaceous plants, which are shallow-rooted and show the most vigorous growth with frequent applications of water. Since in this case, moisture is removed from the surface both by evaporation and by root absorption, water is more often a limiting factor. On the other hand, fruit trees, as a result of their deeper rooting, possess a much larger water reserve, and any visible stress is not so quickly apparent.

Effect of moisture supply upon rate of fruit growth. As a means of approach to this problem, investigators have observed the response of the fruit tree as the water in the soil is allowed to fall from the moisture equivalent or the field capacity to the wilting percentage.

In California experiments of Hendrickson and Veihmeyer,[20, 22, 23, 45, 47] peach, plum, pear, and grape plants have been grown both in pots and in the field. Their procedure was to allow a gradual reduction of soil moisture until it reached the wilting percentage, in the meantime taking frequent measurements of fruit growth and the moisture content of the soil. Soils varying from fine, sandy loams to clay adobe were used with fairly similar results. In a few cases the rate of fruit growth showed a reduction before the wilting percentage was reached, but, taken as a whole, their results show that the range from the moisture equivalent, down to within a few points of the wilting percentage was equally satisfactory in maintaining the rate of fruit growth.

In the eastern United States, similar experiments with fruit trees in the field have, in general, substantiated these conclusions. Using a very shallow soil at Hancock, Maryland, the growth rate of apple fruits was shown to be retarded shortly before the wilting percentage was reached in the upper foot of soil.[33] In another experiment [10] peach fruits showed reduction in growth rate when the soil in the upper 2 feet was 3 to 4 per cent above the wilting percentage. In the Hudson Valley region in New York the rate of fruit growth was checked at approximately the same point on apple trees rooting in 2 feet of soil.[4] Trees with roots extending to a depth of 4 feet, in a soil above the wilting percentage, continued to grow unchecked. In the Northwest, Delicious fruits on trees in a dry, sandy loam increased in volume at the same rate as those on trees in the moist plots, until the upper layer of soil reached the wilting percentage. Furthermore, they increased at the same rate as trees in a soil maintained at field capacity.[17]

Totally different results have been obtained in certain heavy soils in Oregon.[31, 32] Fruits on pear trees in the Meyer clay adobe and Meyer silty clay loam (field capacity varying from 25 to 35 per cent) were checked in growth when the available water had been reduced only 30 per cent.

Moisture studies indicate, in general, that water ranging in amount from the field capacity to the wilting percentage can be removed in soils which do not contain too high a proportion of clay with sufficient rapidity to result in little or no reduction in fruit growth. On the other hand in the heavier soil types, the slower rate of capillary movement (even through short distances) prevents absorption of water at a sufficient rate to maintain fruit growth unretarded through the entire range from the field capacity to the wilting percentage.

Experiments show that, once the wilting percentage is attained, the reduction in fruit growth depends upon further prolongation of the period. If irrigation follows immediately, little reduction in fruit size may be noticeable at maturity. On the other hand, in case the moisture content continues near the wilting percentage for several days, a permanent reduction will occur, even though the rate of growth accelerates greatly upon addition of water.

Effect of decreasing soil moisture upon growth of shoots, spurs, and roots. Data regarding the effect of decreasing soil moisture upon the vegetative growth of the tree are inadequate. From available evidence it is assumed that the growth of shoots and spurs is not appreciably affected, since, under orchard conditions in the East, their growth has usually ceased by the time water deficits have become serious. Further data are necessary, however, in this connection.

It is interesting to note that water studies show that the diurnal movement of stomates is affected before the soil moisture reaches the wilting percentage. The closure of the stomates appears to be a delicate index of a disturbance in the water metabolism of the tree. Apparently as a result of the earlier closing of the stomates, water is conserved.

The observations by Rogers at East Malling in England of roots growing in a sandy loam soil are interesting in this connection.[40] By means of specially constructed observation trenches roots were observed in the orchard during the entire year. Root growth was definitely retarded by fluctuations in the moisture content of the soil while it was still considerably above the wilting percentage. This raises the interesting probability that while the rate of fruit growth may not be affected by moisture contents considerably above the wilting point, growth of various portions of the fruit plant may be distinctly retarded.

Results of studies with small fruits. Similar studies with reference to the growth of small fruits are few. In Michigan [34] black raspberry plants were grown with a high soil moisture (ranging from 17 to 24 per cent) during two seasons. The wilting percentage was 8 to 9. The plants at the high moisture content showed 77 to 121 per cent greater leaf area than those at the lower moisture content.

Water supply as related to dessert and keeping qualities of fruits. Various experiments indicate that the dessert and keeping qualities of peach, plum, grape, pear, and apple were not detrimentally affected when the moisture supply of the soil was permitted to fall temporarily to the wilting percentage.[20–23]

General experience indicates, however, that both *extremes* of moisture are undesirable as far as the color, composition, dessert, and keeping quality of fruits are concerned. On plants suffering from extreme water deficiency, water is removed from the fruits by the leaves, and as a result the fruits may lack color, become tough, and somewhat "meaty" without the crispness of fruits having a higher water content. On the other hand, when water is excessive, the color may again become less attractive and the keeping quality impaired. In small fruits such as the strawberry the water content may be increased, and the sugar and acid so modified as to result in a distinctly less pleasant flavor.[11, 30] In addition the fruits will not as readily undergo handling and shipping. Strawberries on irrigated plots were larger and softer than on unirrigated plants.[30]

In the Northwest [41] Bartlett pear fruits grown on trees in continuously moist plots were lower in dry matter and less firm than fruits on trees in dry plots. Core breakdown was also more frequent. The water content of Anjou pears at harvest correlated with the amount of available water in the soil.[42] Pressure tests indicated that fruits growing under a higher degree of moisture were softer and yellower when ripe, and in addition proved to be more susceptible to soft scald. Drier plots produced more acid fruits and a better flavor generally. In addition surface scald occurred more frequently on fruits grown in moist areas.

California peach fruits which had been subjected to a continuously high moisture content and then stored both at 70° F. and in common storage, showed more bruising and decayed more rapidly than fruits grown on soil having a lower moisture content.[20] It appeared also that the canning quality of the fruits was not impaired by a reduction in water so long as fruit growth remained unaffected. There seemed to be no appreciable difference in sugars and acids between fruits from the moist and those from the dry plots unless the trees were subjected to prolonged drought.

In Washington [37] the percentage of extra fancy Jonathan apples and of fruits with total red overcolor was less on medium and heavily irrigated plots than on those lightly irrigated. The lightly irrigated plots produced fruits of the highest quality, and were reported to net the greatest return to the grower. Injury by bruising and handling was also greater on oversized, highly irrigated fruits. Furthermore, when stored at room temperature the fruits decayed more rapidly. Thus the data indicate, and general observation concurs in the opinion, that excessive irrigation may have a detrimental effect upon fruits.

Essential Elements in Relation to Water Supply

A deficiency of certain of the essential elements has been definitely shown to disturb the water metabolism of fruit plants. Potassium and calcium are particularly noteworthy in this connection.

Potassium. Potassium and water metabolism are notably interrelated. Plants deficient in potassium show less turgidity and are inclined to wilt when transpiration is high, even though the moisture supply is adequate. Thus when moisture is actually low, wilting frequently occurs. The reduced turgidity of apple shoots, coincident with potassium deficiency, was recently shown to be caused by their apparent inability to transmit water.[51] These results indicate the very serious effect of potassium deficiency upon the water content of plant tissue.

Calcium. Nutrient deficiency studies invariably show that root growth is more adversely affected by a lack of calcium than by the deficiency of any other essential element. The fine roots tend to be bulbous, brown, less efficient in water absorption, and quite susceptible to decay. In view of this fact, under conditions favoring high transpiration, considerable water stress may be evident.

Relation of Cultural Practices to Water Supply

Fruit growers who resort to irrigation must adjust other practices accordingly, if the maximum benefit is to be obtained.

Thinning. In Oregon it was found that when water is fully maintained, pear fruits may be easily overthinned, in consequence becoming oversized.[1] A similar adjustment, involving lighter thinning is necessary in the case of apples.

Nitrogen fertilization. The application of nitrogen fertilizers tends to increase the growth of the above-ground portion of the plant, as compared with the roots. Thus the $\frac{\text{top}}{\text{root}}$ ratio is unbalanced, and an increased amount of moisture is required in order to prevent water stress. Furthermore, soft, succulent leaves and stems, such as excess nitrogen applications produce, transpire water more readily than organs growing less actively. Since nitrogen applications are required for almost all fruit plants, compensation for the increased amount of water required must be judiciously adjusted by means of other practices.

IRRIGATION OF TREE AND SMALL FRUITS

In the Western fruit-growing regions of the United States where rainfall is deficient, irrigation is an established practice. In the East, irrigation, although adopted by a number of growers of tree and small fruits, has never become a generally accepted means of maintaining a satisfactory water supply, in spite of the fact that growers have reported favorable results when, previous to irrigation, droughts had decidedly reduced the size and quality of the fruit. Although in some such favorable reports the same end might perhaps have been obtained by more economical means, yet under certain conditions no other method will answer. In the small fruits, such as the strawberry for instance, droughts during the picking season not infrequently reduce both the number of pickings and the quality of fruit in later pickings.

The fruit grower who is contemplating irrigation in the more humid regions of the East should study his local conditions sufficiently to determine whether a favorable moisture supply can be maintained by more economical means. Secondly, consideration should be given to the weather records in order to determine the frequency of droughts, and the proportion of the years in which drought extends over one month should be noted. An irrigation system which is of value only one year out of five is a questionable expenditure. And yet on some sites where the depth of rooting of tree fruits is shallow (12 to 24 inches) irrigation may be the only means of maintaining a satisfactory water supply. Under other conditions mulching may prove preferable, and then comparative costs of both should be calculated. Finally the grower should consider whether the previous history of the planting indicates that water applications might produce desirable results in growth and fruiting.

One of the principal factors determining the feasibility of irrigation is the source and abundance of the water supply. Under Eastern conditions numerous irrigation systems have been installed where the sources of water are inadequate. Under Western conditions many sources are unsatisfactory from the standpoint of salt content. In the East no system should be installed where an abundant source of water cannot be available during the summer months. It must be ascertained that streams which are to be utilized will not dry up when water is particularly needed. Wells will hardly serve where large acreages are to be irrigated although they may be sufficient for small fruit plantations. Hardly less than 2 inches of water should be applied to an acre at one irrigation, an amount which is equivalent to 54,000 gallons.

Methods of Applying Irrigation Water

Four methods of irrigation are in common use, namely, furrow, basin, sprinkler, and porous and eyelet hose. Each method is adapted to certain specific conditions. The orchardist must study his soil, topography, water supply, and other local factors in order to determine which method will best suit his requirements. The following discussion is largely one of method, and does not attempt to cover the engineering features involved in irrigation. Only the porous and eyelet hose method is considered since the other methods are discussed in readily available publications.[13, 27, 37, 49]

Porous and eyelet hose method of irrigation. Porous canvas hose has been used as a means of irrigating sites on steep slopes which are not adapted to sprinkler irrigation. The porous hose method is ordinarily considered to be more economical than the sprinkler system since less piping and expensive equipment is needed, although the permanent sprinkler systems are found to be somewhat more economical as far as the labor is concerned.

A water pressure of only 1 to 2 pounds per square inch is needed for canvas hose systems.

The most desirable type of hose is secured by using high quality canvas made of long fiber cotton, and without filler. Either 8- or 12-ounce canvas may be used depending on the size of the hose desired. The hose may be made up at a local shoe repair shop with heavy thread and for convenience in handling should be in sections 50 to 100 feet long.

Good connectors by means of which hose ends may be fastened together may be made from one foot lengths of galvanized pipe. Such fittings are also useful as a means of attachment to the main pipe line. The hose ends are quickly fastened by using leather or web straps.

A canvas hose will lie on irregular ground and may often be placed in such a manner as to partially dam up, and direct the water, to insure uniform distribution. The water should be allowed to run as long as necessary to properly moisten all land within reach of the hose.

The ooze hose method has several advantages: it is useful in locations having an irregular contour; foliage is not watered; erosion is retarded. The disadvantages are: rate of application is not always fast enough; water is applied only at a limited distance from the hose, thus necessitating considerable movement of hose; care must be used in cleaning and caring for hose to prevent rapid disintegration and decay. The fact that the foliage need not be wetted is a factor of importance in disease control and sometimes in fruit rot prevention. Mulching materials cause no appreciable interference and often help to keep the hose clean.

Canvas hose irrigation has assumed appreciable importance in the last few years as a flexible system for applying water to various crops. Small fruits, and especially strawberries are well adapted to this system when the ground is uneven or the soil porous, and where sprinkler systems are considered too expensive.

To overcome, in part, the disadvantages of ooze hose, eyelets have been placed in army duck at intervals of 2 feet in order to produce alternating jets of water, at some distance on each side of the hose. With considerable pressure these jets have delivered water laterally up to 20 feet, and in addition, the rate of application is faster. The hose is now chemically treated before use, a fact which greatly reduces the decay of fibers. The use of eyelet hose is probably the preferable manner of applying water to tree fruits with ooze hose restricted to the small fruits.

Time and Amount of Water Application

When to apply water. Even though an irrigation system for tree fruits has been installed, and additional water is thus available, it is not easy to determine the exact time at which the application should be made. Since a number of factors are involved, a general recommendation is impossible. As noted above, the soil type is important and may, under certain circumstances, permit the postponement of applications until the moisture content approaches the wilting percentage. On the other hand, in certain heavy soils, such as the Meyer silty clay loam, the moisture content must be kept high. It is probable, however, that the best fruit soils show a considerably wider range of moisture content at which the growth rate of the fruit remains unchecked. In general, present evidence indicates that the first application to tree fruits can be delayed until the moisture content of the soil in the area of greatest root concentration has been reduced nearly to the wilting percentage. But in case water is abundant and facilities for its application are available, growers may not want to delay so long. On the basis of present evidence, however, it seems probable that the application of water before this point is all but attained, may have little immediate effect upon the plant, except to increase the reservoir supply. In the West, however, fruit growers usually apply water even before it is immediately essential in order to maintain the supply, as insurance against future necessity.

Indices used to determine the time to start irrigation. Several indices have been suggested as a means of determining in the field the time to make the first or subsequent applications of water. These are: (1) comparison of the soil moisture in the region of the greatest root concentration with the wilting percentage previously obtained; (2) measurement of the rate of fruit growth; (3) use of the evaporation index; (4) observation of indicator plants; and (5) amount of rainfall deficiency.

Soil moisture in rooting zone compared to wilting percentage. Since water is removed most rapidly from the area of greatest root concentration, examination of the soil should be made in this area, which amounts to a circle, whose radius extends from 2 to 10 feet from the trunk (depending upon the size of the tree) and down no farther than 2 feet from the surface. Here soil samples should be taken to determine the dryness of the soil in relation to the wilting percentage. The use of this index as a means of determining the time to irrigate is not entirely satisfactory from a practical viewpoint, since it involves a knowledge of the wilting percentage of the particular soil and requires frequent soil moisture determinations which are not readily made by all growers.

Measurement of rate of fruit growth. Another suggested index is the rate of fruit growth.[16] The rate of enlargement of representative fruits on typical trees is frequently measured with the intention of determining the time when the rate shows its first slight reduction, due to lack of sufficient water. At this point water is immediately applied. From a practical viewpoint this index is of questionable value since most growers would be unwilling to wait until fruit growth was actually retarded, provided they have facilities and equipment for irrigation.

Use of the evaporation index. Recently water has been applied to strawberry and other horticultural crops in proportion to the amount of water evaporated, which is measured by instruments showing the rate of evaporation.[35] In these experiments a given amount of water is applied for every inch of water lost. This method has promise with certain crops, since it takes into account the environmental conditions which accelerate transpiration from the surface of the leaves. However, the amount of water which must be applied to replace a given amount of evaporation must be previously determined by experiment.

Observation of indicator plants. At present this method seems to have no practical value.

Amount of rainfall deficiency. In the East fruit growers have used the average rainfall per month during the summer as an index of the amount of water satisfactory for growth and fruiting. They have arbitrarily applied water to at least the equivalent of the normal rainfall in applications of 2- to 3-acre inches each. Where water is abundant and irrigation costs are not excessive, the grower has found this a fairly satisfactory index of the time and amount of application.

Amount of water to apply. The amount of water to apply when irrigating depends upon three factors: (1) the capacity of the particular soil to hold water (moisture equivalent or field capacity); (2) amount of water already present in the soil or its initial moisture content; and (3) depth to which the soil is to be irrigated. The first two factors have already been discussed earlier in the chapter.

Depth of soil to be wetted. The depth which is to be wetted depends upon the depth of rooting of the plants. With surface, or superficially rooted plants such as the strawberry, the entire depth to which the roots extend should be reached. With fruit trees, the depth to be irrigated depends somewhat upon the depth of the greatest root concentration. Trees in a soil confined to a rooting of 2 to 3 feet, because of rocks or impenetrable hardpan, should be irrigated to the entire depth of rooting. When roots extend to deeper layers (4 to 6 ft.) at least 3 feet should be brought to field capacity. With lighter types of soil it may be desirable to wet an even greater depth.

Obviously, in order to affect the lower levels water must be applied at the surface and percolate through. Thus in order to prevent waste, the water must not be applied at a rate more rapid than the rate of percolation, which in some cases is so slow as to greatly retard the operation.

All authorities on irrigation agree that the amount of water applied should be sufficient to bring the *entire mass* to be irrigated up to the moisture equivalent or field capacity. In other words, the water reservoir of the soil should be filled whenever an application is made. This means that, for a short period, while percolation is occurring (1 to 6 days usually, depending on the soil type) the moisture content of the surface soil will be above the moisture equivalent.

In the West it has been found less costly and more effective to raise the moisture to field capacity at each application rather than to make more frequent applications which only wet the surface and are insufficient to reach the lower soil horizons. Furthermore, this light irrigation tends to result in considerable surface rooting. Experiments show that an application of water will wet to field capacity a single layer corresponding to the amount applied, rather than wetting the whole area to a slight degree. For example, if 2.5 inches of water are required to wet 1 foot of soil to field capacity and 1.25 inches of water are applied, 6 inches of soil will be wet to field capacity with the lower 5 to 6 inches remaining dry.

TABLE 19. DEPTH OF IRRIGATION WATER IN INCHES REQUIRED TO ADD VARIOUS PER CENTS TO ONE FOOT OF SOIL FOR SOILS HAVING DIFFERENT APPARENT SPECIFIC GRAVITIES*

(*After Israelsen*)[27]

Moisture Per Cents Needed P'w	*Apparent Specific Gravity* (As)							
	1.2	*1.3*	*1.4*	*1.5*	*1.6*	*1.7*	*1.8*	*1.9*
1.0	.14	.16	.17	.18	.19	.20	.22	.23
1.5	.22	.23	.25	.27	.29	.31	.32	.34
2.0	.29	.31	.34	.36	.38	.41	.43	.46
2.5	.36	.39	.42	.45	.48	.51	.54	.57
3.0	.43	.47	.50	.54	.58	.61	.65	.68
3.5	.50	.55	.59	.63	.67	.71	.76	.80
4.0	.58	.62	.67	.72	.77	.82	.86	.91
4.5	.65	.70	.76	.81	.86	.92	.97	1.03
5.0	.72	.78	.84	.90	.96	1.02	1.08	1.14
5.5	.79	.86	.92	.99	1.06	1.12	1.19	1.25
6.0	.86	.93	1.01	1.08	1.15	1.22	1.30	1.37
6.5	.94	1.01	1.09	1.17	1.25	1.33	1.40	1.48
7.0	1.01	1.09	1.18	1.26	1.34	1.43	1.51	1.60
7.5	1.08	1.17	1.26	1.35	1.44	1.53	1.62	1.71
8.0	1.15	1.25	1.34	1.44	1.54	1.63	1.73	1.82
8.5	1.22	1.33	1.43	1.53	1.63	1.73	1.84	1.94
9.0	1.30	1.40	1.51	1.62	1.73	1.84	1.94	2.05
9.5	1.37	1.48	1.60	1.71	1.82	1.94	2.05	2.17
10.0	1.44	1.56	1.68	1.80	1.92	2.04	2.16	2.28
10.5	1.51	1.64	1.76	1.89	2.02	2.14	2.27	2.39
11.0	1.58	1.72	1.85	1.98	2.11	2.24	2.38	2.51
11.5	1.66	1.79	1.93	2.07	2.21	2.35	2.48	2.62
12.0	1.73	1.86	2.02	2.16	2.30	2.45	2.59	2.74
12.5	1.80	1.94	2.10	2.25	2.40	2.55	2.70	2.85
13.0	1.87	2.02	2.18	2.34	2.50	2.65	2.81	2.96
13.5	1.94	2.11	2.27	2.43	2.59	2.75	2.92	3.08
14.0	2.02	2.18	2.35	2.52	2.69	2.86	3.02	3.19
14.5	2.09	2.26	2.44	2.61	2.78	2.96	3.13	3.31
15.0	2.16	2.34	2.52	2.70	2.88	3.06	3.24	3.42

Technical method of calculating amount of application. To apply water intelligently, the moisture-holding capacity of the soil as represented by either the moisture equivalent or the field capacity, and the amount of water remaining in the soil at the time of application should be known. The exact procedure to be followed in determining, from the known factors, the amount of water required for an application is as follows:

Samples of soil are taken to a depth of 2 feet from the area of greatest root concentration, and their moisture determined. Subtract the percentage obtained from the moisture equivalent or field capacity of the soil. If the moisture equivalent is not known, an approximate moisture equivalent as indicated by the value given in Table 18 can be used. The difference represents the moisture (in per cent) which must be added to the soil to bring it to field capacity, and the amount equivalent to this percentage can be found in the first column of Table 19.

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* Based on equation $d = \frac{P'w \text{ As } D}{100}$. See Table 18.

In the column to the right corresponding to the particular *apparent specific gravity** of the soil is found the amount of water in inches which will bring one foot of the soil over an acre area from its present moisture content up to the moisture equivalent or the field capacity. This value expressed in acre inches is multiplied by the number of feet to which it is desired to wet the soil. Multiplying the acre inches required by 27,150 will give the amount of water to be applied in gallons. Obviously the amount of water which it is estimated will be lost by run-off must be added.

An example will clarify the procedure. A silt loam soil with a moisture equivalent of 21 per cent is found to be 13 per cent water when a sample is dried. To wet this soil to the moisture equivalent, 8 per cent of water is thus required. Assume that the silt loam soil has an apparent specific gravity of 1.4. To convert the 8 per cent to inches, Table 19 is•consulted and the value located in

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* The *true* specific gravity or density of a soil is the weight of a given volume of soil (without air spaces) compared to the weight of a like volume of water. The true specific gravity of most mineral soils free of organic matter is approximately 2.65. As soils exist in the field, however, a considerable quantity of air is held between the particles. This is a normal and desirable condition and, therefore, to acknowledge this situation, the apparent specific gravity of a soil refers to the weight of a given volume of soil including the air spaces it contains under field conditions, compared to the weight of a similar volume of water. The volume weight or apparent specific gravity of different soil types is given below. The appropriate value for the given soil type for use with Table 19 is to be found in Column 2.

Soil Type	*Volume Weight* [a] *(Apparent Specific Gravity)*	*Total Pore Space* [b] *Per Cent by Volume*
Sandy soil	1.79	32.49
Sandy soil	1.74	34.45
Sandy loam	1.62	38.83
Loam	1.48	44.15
Clay loam	1.40	47.10
Fine clay soil	1.38	48.00
Finest clay soil	1.25	52.94

[a] Computed from the equation

$$\frac{\text{Total pore space}}{\text{(per cent by volume)}} = 100 - \left(\frac{\text{Volume weight}}{\text{Specific gravity}} \times \frac{100}{1}\right)$$

[b] From King, F. H., *A Textbook of the Physics of Agriculture.* Published by the author. Madison, Wisconsin, 1910. Page 126.

Column 1. The amount of water for a soil with 1.4 apparent specific gravity is given in Column 4. In this column opposite the 8 per cent is the figure 1.34. Thus 1.34 inches of water are required to raise the soil moisture in a 1-foot layer, over an acre, from 13 per cent to the moisture equivalent. In gallons the amount required is 36,380. If this value is multiplied by 3, the amount required per acre to a 3-foot depth will be 109,000 gallons.

Irrigation of Specific Fruits

Peach. The peach is irrigated in those regions where moisture deficit would otherwise prevent successful culture. Experiments indicate that the period beginning with the end of pit hardening and continuing until the fruits reach maturity is the most critical, thus necessitating a sufficient supply of water during the last few weeks of fruit growth in order to induce maximum size of fruit.[10] No amount of water applied early in the season compensates for lack of water during the month before harvest.

Small fruits. Irrigation of small fruits, particularly the strawberry, has been successfully practiced for some time. Irrigation of the blackberry and raspberry, while it has been shown to increase the yield, has never been extensively adopted except in localities where irrigation of other fruits is also common.

Wherever moisture supply has limited strawberry production, irrigation put into effect during the first year (in which the plants are not allowed to fruit) has resulted in larger plants, greater runner formation, and more flower buds for the succeeding year's crop. During the fruiting year irrigation has notably increased the length of the picking season and increased the yield and quality of the last pickings.

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9

THE PRUNING OF FRUIT PLANTS

The pruning of plants has had a prominent place in horticultural literature from the earliest writings up to the present. In the early days instructions consisted largely of detailed methods for obtaining the ideally shaped tree; thus they were concerned with the art of pruning rather than with the effect on the growth and reproduction of the plant. The European literature on the subject is voluminous and is usually accompanied by drawings of the various training methods employed. The European gardeners have given particular attention to training trees to unusual forms. In commenting on the extent to which traditions have influenced opinions in regard to pruning, Bedford and Pickering,[9] who were among the first to publish results of pruning experiments, aptly describe the situation as follows: "As an art it does not lend itself very freely to scientific investigation, and where scientific investigation can be brought to bear on it, the teachings of the artist have not always been confirmed."

Only within the last quarter century have the results of experiments, planned to study the effect of pruning upon growth and fruiting, been published, and even now it cannot be said that there is agreement on a number of important points. The art is still interwoven with the science to a considerable degree, and all pruning practices when critically examined, cannot be said to have a firm scientific basis.

Definition and Purpose of Pruning

Pruning may be defined as the art and science of cutting away a portion of the plant to improve the shape, to influence its growth, flowering, and fruitfulness, to improve the quality of the product, or to repair injury. Its purpose at any specific time depends upon several factors: (1) the age of the plant; (2) its vigor;* and (3) whether it is bearing or nonbearing. At planting time and during the few subsequent years, the purpose is primarily to train or shape the tree so that the scaffold branches will develop strong, wide-angled crotches, capable of bearing fruit without breakage. This training should develop a framework capable of supporting large yields of high-quality fruit when the trees reach bearing age. The purpose in America is not to create a beautiful object but rather to obtain a tree that is commercially profitable within a reasonable period of time. Furthermore, it is essential to train the tree so as to avoid susceptibility to low temperature injury such as sunscald, and so as to facilitate orchard operations such as spraying, thinning, and picking.

In the bramble fruits and in the grape, less emphasis is placed upon training to prevent breakage than upon the development of a plant capable of yielding the largest quantity of fruit of the desired quality. In addition, pruning aids in shortening the ripening season of the fruit, which is usually a desirable objective.

Importance of Growth and Flowering Habits

There is an increasing tendency in pruning practice to emphasize the varietal aspects of the operation. Until recently recommendations were based upon the kind of fruit only, but experience has shown that in order to produce the most effective results it is necessary to consider the growth and flowering habits of specific varieties. As yet relatively little information of this sort is available, but the future will doubtless find the knowledge of this phase considerably enlarged, not only in the tree, but also in the small fruits.

Pronounced differences in growth habits are apparent in the different varieties of the tree fruits. One variety tends to develop spreading, horizontal branches while another may exhibit an upright growth. In the first instance, pruning should be designed to stimulate the upright branches, preventing impingement on each other and the formation of an interlocking thicket. In the other case, the cuts should induce a spreading growth in order to facilitate spraying, thinning, and picking. All varieties do not respond in the same manner to heading-back cuts, and care must consequently be exercised in adapting this type of pruning to such varieties. In addition, varieties differ considerably in the proportion of small branches produced. For example, the Baldwin and Jonathan apple varieties tend to produce many small branches which have a tendency to thicken the interior of the tree rather rapidly. On the other hand, the number of small branches produced by Stayman Winesap is much less, and in this case pruning may be even more easily overdone.

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* Vigor as here used is not synonomous with vegetative growth. Mere extension in length without a proportional increase in diameter does not imply vigor, for even an etiolated shoot may show considerable extension in length. The latter does imply a vegetative but not a vigorous condition. Vigor assumes a well-balanced growth in both length and thickness. Accompanying this type of growth are large, dark-green leaves.

In connection with the flowering habit, it is also desirable to be familiar with the location of flower buds. One variety may show bud differentiation chiefly upon shoots, another on spurs, while still others form their flowers upon both. Obviously, heading back the terminal growth would remove a greater proportion of the flower buds in one case than in another. In another instance, a variety whose flower buds were formed largely on shoots at the periphery of the tree would be less likely to show decreased flower formation as a result of insufficient light at the interior of the tree. In the small fruits, such as the raspberry and the grape, it is desirable to know, first, the location of the buds which grow into flowering shoots, and secondly, the relative fruitfulness of these buds. There are differences between varieties in the number of flowering shoots produced by a given length of lateral. One variety may have shorter internodes than another, in which case pruning recommendations made on the basis of length for one variety are unsatisfactory for the other. Varieties also differ in the fruitfulness of buds along the laterals and closely adjacent to the main cane. Examples of this characteristic are indicated in the detailed discussion of pruning.

Effect of Pruning upon Growth

Pruning experiments have invariably shown that pruning is a dwarfing process. Bedford and Pickering [9] in England and Chandler [12] in America were among the first to demonstrate the fact that, although the immediate effect of pruning is to increase the length of shoots and the size of leaves, total growth attained by an unpruned tree is always greater than that of a pruned tree regardless of the *type* or *amount* of pruning. The growth incurred in response to pruning does not compensate for the portion removed by pruning plus the growth which would normally occur at that point, although pruning does give an optical illusion of increased growth. Furthermore, the trunk and branches of the unpruned tree will show a greater thickness, as opposed to length, which fact contributes to the greater weight of the unpruned tree, as demonstrated by experiments showing the actual weight of pruned and unpruned trees.[12]

Pruning not only reduces the total growth made by the above-ground portions but the total root growth as well. In fact, a heavy pruning, carried out for several years, reduces the rate of root growth to such an extent that it becomes decidedly detrimental. Experiments indicate that root growth is dependent upon a satisfactory supply of materials produced by the leaves,[12] probably phytohormones as well as carbohydrates. Therefore, whenever pruning, indirectly but drastically, reduces these substances, the rate of root growth is reduced to a corresponding degree.

The extent of the reduction in total growth following pruning is roughly proportional to the severity of the pruning, that is, to the number of potential buds and leaves removed. The beneficial effects of pruning, i.e., increased size of leaves and a decrease in the exhaustiveness of fruiting, compensate in part for its dwarfing tendency and for the loss of leaves. Obviously, this beneficial effect can more nearly equalize a small loss than a heavy one. Hence the advisability of light pruning. As a matter of fact, in some cases, a very lightly pruned tree is only slightly smaller than a heavily fruiting, unpruned tree.

Summer pruning versus dormant pruning. There is an old saying, "prune when the knife is sharp," but this old adage has not been supported by experimental evidence. Experiments comparing summer and dormant pruning invariably indicate that, for the amount of wood removed, summer pruning has a greater dwarfing effect than dormant pruning.[1, 2] The leaves to be removed by summer pruning have only recently achieved a functional status, and at the expense of a considerable amount of nutrient materials stored in the wood and bark. Removal at this time prohibits the leaf function, which is the replacement of carbohydrates, and thus the tree that has been exhausted by leaf production, is deprived of their future product.

For this reason, any pruning, which takes place in June or July after the seasonal growth has begun, has a more reductive effect than the same practice carried out either earlier or later. In a pruning experiment at Ithaca, New York, a young apple tree was pruned on July 9 to a degree which amounted to a 48 per cent reduction in leaf surface. By November 5, the weight of the roots was 15 per cent less than the root weight of the control tree.

Summer pruning has never been widely adopted either by fruit growers or professional horticulturists in this country. However, removal of water sprouts is often practiced in early summer at a time when the succulent sprouts can be rubbed off quickly and easily, often without the use of pruning tools. Growers occasionally remove some wood after the trees have leafed, but this is the result of failure to complete the dormant pruning.

In addition to the growth reduction, summer pruning may considerably prolong the growth of shoots. This growth prolongation may increase the susceptibility to low-temperature injury, an effect associated with the failure to accumulate reserve carbohydrates.

Localization of the effects of pruning. Growth in response to pruning has its most pronounced effect upon those branches, shoots, and spurs immediately surrounding the pruning cut, even though the general effect may extend throughout the tree. It would appear that the growth response decreases as the distance from the cut increases. On the other hand, pruning by reducing the surface area, increases the water supply available to the remaining growing points, and for this reason produces an effect upon growth in relatively distant portions of the tree. But in general each pruning cut may be said to possess its own "sphere of influence" within which it produces a special response in growth. For instance, Kieffer pear trees which are annually cut back in the "tops" will manifest a "brooming" growth which is completely unfruitful at and near the wounds, yet the lower portions of the trees will bear abundantly as though no pruning had been done.

Bulk pruning which removes large limbs and branches produces such a decided effect near the cuts that water sprouts often become excessive. A more detailed method will remove smaller branches and twigs and is designed to head back the large, undesirable limbs by degrees and not all at one time. Such a method dwarfs large branches gradually and results in fewer water sprouts and growth readjustments. This detailed or distributive type of pruning is considered preferable, but the time and expense involved have prevented its widespread adoption in practice.

Effect of Pruning upon Flower-bud Formation

One of the most outstanding effects of pruning occurs in relation to flower-bud formation. The commercial motive which is the decisive factor in all orchard practice must in this case differentiate between young and old trees, for the same degree of pruning which is beneficial in case of mature trees may prevent fruit production in the case of the young, nonbearing orchard.

It is undoubtedly true that in the case of young trees which have not yet flowered, pruning delays the differentiation of floral primordia. It was found in Michigan, for instance, that severely pruned sour cherry trees showed a 3- to 5-year delay in fruiting as compared with lightly pruned trees.[51] In general, this delay appears to be more or less proportional to the degree of pruning.[12, 53]

The retardation results partly from the fact that pruning, insofar as it stimulates and prolongs the vegetative growth of shoots and spurs, at the same time delays the accumulation of those materials manufactured by the leaves which evidently induce flower-bud formation. The same materials are concerned in the formation of flowers and in the growth of shoots and spurs, and when these materials are completely utilized in the production of vegetative growth, flower buds are not formed. Furthermore, those varieties of the apple and pear which flower largely upon spurs will show a pronounced delay in flower formation so long as the tree is stimulated to produce long, rank shoots upon which few or no flowers develop. A *heading back* cut appears to delay flowering rather more than the *thinning out* cut, a result due probably to the succulent growth which frequently occurs in the region now distal because of the heading back. At this point vigorous shoots may develop resulting in still greater retardation of flower formation.

Pruning fruit trees during the first few years of flowering, although it still produces vigorous shoot growth, rarely entirely inhibits the formation of flowers. The flowering process once it is initiated, is not easily suppressed. Nevertheless, pruning does remove flower buds differentiated the previous year, thus reducing the total bearing surface. Furthermore, the invigorating effect of the process, which increases the set in mature trees, is quite unessential in young trees which are already sufficiently vigorous. Pruning with its stimulation of more shoots and spurs, produces its most positive and beneficial effect on older trees which have borne heavily for a number of years. The production and maturation of fruits has an exhaustive effect and tends toward a decided reduction in growth of shoots and spurs. Thus the number of potential flowering points is considerably reduced. Pruning by removing a number of flowers and stimulating a "vigorously vegetative" type of growth results in new wood, which in turn will bear its quota of flower buds. The sour cherry furnishes a rather extreme example of the effect of pruning on bearing trees. A sour cherry tree, low in vigor, tends to form flower buds at nearly all nodes on shoots and spurs, while leaf buds occur only at the terminal position. Since the flower buds are simple, no shoots develop, and consequently the twigs are left bare as soon as the flowers abscise or the fruit is harvested. Pruning, by increasing the vigor of the shoots, reduces the proportion of flower buds. Furthermore, as the proportion of leaf buds increases, more shoots are produced and thus the yield is eventually increased.

Pruning a weak, devitalized tree has been known to increase its fruitfulness, but this is largely due to an effect upon fruit setting which will be discussed later.

Observations show that some flower buds tend to differentiate even on trees quite deficient in nitrogen (possessing a large supply of carbohydrates because they are not utilized in tree growth). In those cases where nitrogen has become quite deficient and flower formation is at a minimum, pruning, by increasing the supply of nitrogen available to the remaining growing points, tends to increase the differentiation of flowers as well.

Effect of Pruning upon Fruit Setting

Pruning tends, almost invariably, to increase the percentage of flowers which develop into fruits. The elimination of certain growing points indirectly increases the supplies of water and nitrogen available to the remainder. Although pruning does have this effect, even on trees already making a good growth, fruit setting is more satisfactorily maintained by the application of nitrogen, since pruning alone would involve too great a reduction in potential bearing surface. In Michigan [42] the set of fruit on unfertilized apple trees was increased by pruning, but the extent of this increase was considerably less that that induced on unpruned trees by an application of a nitrogen carrying fertilizer. It is rather in the case of certain varieties which, despite nitrogen application, still set lightly, that pruning has a particularly beneficial influence upon fruit setting. It has been shown, for example, that the lighter setting apple varieties such as Rhode Island Greening [28] and Delicious, as well as the relatively unproductive pear variety, Beurré d'Anjou,[3, 46] are favorably affected by pruning when other practices fail to increase the set materially.

Effect of Pruning upon Yield

The pruning of tree fruits, as indicated by a number of experiments, usually results in a reduction in total yield.[12] Exceptions occur in the case of trees too dense, or devitalized trees, which, in spite of flowering, set relatively few fruits. Certain varieties, such as the Beurré d'Anjou pear, also appear to be exceptional in their response to pruning, but in general the variety is a secondary factor in a general consideration of yield in response to pruning. Aside from the exceptions mentioned above the amount of reduction in total yield is roughly proportional to the severity of pruning.

Within the last fifteen years the Michigan Station [42] has emphasized the fact that pruning may easily be done at the expense of total yield. The results of a recently published Ohio experiment,[20] further emphasize this fact.

The effect of pruning upon the yield of marketable fruit is the important point. Fruit growers are faced with a very practical problem in determining the amount of pruning which will produce favorable effects and yet not reduce the marketable yield unnecessarily. There has never been general agreement as to the proper adjustment of pruning to other practices, such as thinning, in order to achieve the greatest yield of marketable fruit and the most favorable net return.

The effect depends in part upon the condition of the tree at the time of pruning. Where the trees are dense and would shade the fruit considerably, a light to moderate pruning tends to increase the marketable yield. On the other hand, if the trees have recently been well pruned and are already open and making satisfactory growth, even a moderate pruning may actually reduce the total marketable yield to the point where the net return is considerably decreased.

Type of pruning in relation to yield. The type of pruning governs the extent to which the practice reduces both the total and marketable yield of fruit. Pruning may consist of large cuts, often termed *bulk* pruning, or it may be *detailed* involving the removal of many small branches well distributed throughout the tree. Pruning may also be of the *heading-back*, or of the *thinning-out* type.

Heading back involves the cutting back of a shoot, twig, or branch, usually to a lateral. It prevents further growth in a particular direction and results in more new laterals and increased growth of all laterals immediately adjacent to the cut. *Thinning out* involves the removal of shoots, twigs, or small branches from positions lateral to the main stem or axis. It does not entail, as does heading back, the removal of the terminal portion of the branch. An example of heading back is the lowering of the height of a tree which has been allowed to grow too tall, while thinning out consists in the removal of the small branches throughout the bearing area which have a tendency to thicken and make it dense. Both types of pruning, heading back and thinning out, are dwarfing in their effect, since they result in the removal of leaves. Both have found their place in pruning practice and should often be used in conjunction. In transplanting large trees (ornamentals) they are usually given a fairly heavy thinning-out type of pruning but not heading back. It has been found, however, that the two methods do not effect an equal reduction in growth. It is usually considered that heading back dwarfs the tree more than thinning out.[55] In addition, the thinning-out type, by eliminating heavy shading, may induce a greater rate of photosynthesis in the remaining leaves. On the other hand, heading back frequently results in a rather pronounced growth of water sprouts in the vicinity of the cut and a rather dense growth.

Effect of Pruning upon Size, Color, and Quality of Fruit

Numerous experiments conducted in widely scattered areas, have demonstrated a definite improvement in size, color, and quality of fruit in response to pruning.[12, 42, 51, 53] Considered from the practical viewpoint these particular factors furnish the most favorable evidence in regard to the effects of pruning.

The color of fruit is unfavorably affected when shading prevents its direct exposure to sunlight. In addition, a dense, unpruned tree which has set heavily, produces fruits of small size and poor color as a result of an unfavorable nitrogen-carbohydrate relationship. In both cases, pruning will be found beneficial. A light, rather than a moderate to heavy pruning will produce satisfactory results in most varieties, but importance of the variety factor is shown in New York where pruning was followed by a greater increase in the size of Baldwin than in the size of Rhode Island Greening apples.[44] This difference probably resulted from the fact that Rhode Island Greening is inclined to set more lightly and thus possesses a more favorable leaf-fruit ratio.

In spite of the fact that pruning does increase the size and color of varieties such as Baldwin, yet obviously it cannot reduce the number of fruits at a fruiting point. This result must be achieved by thinning except perhaps in the case of a few light-setting varieties. Furthermore, any pruning so severe as to obviate thinning in the heavy setting varieties, would at the same time, reduce the marketable yield excessively. The general recommendation in the tree fruits may be stated as follows: although pruning will improve both size and color, more or less in proportion to the amount of wood removed, yet in application, the practice should be light or moderate at the most, with thinning as a supplement in order to maintain a proper leaf-to-fruit ratio.

Pruning and Water Supply

Both dormant and summer pruning temporarily decrease the transpiring surface of the plant, thus reducing any water stress which may have occurred. And inasmuch as water deficits are equalized in the fruit plant, pruning may be expected to reduce the deficit throughout the entire plant. Furthermore, when transpiration is high, the removal of leaf surface may even increase the rate of fruit growth. For example, in Oregon, following removal of 20 per cent of the leaf surface the fruits on pear trees showed a greater rate of enlargement than those on the check trees.[4] One of the effects of pruning is to restore the balance between top and root, if this balance has been previously upset by nitrogen applications which tend to increase the area of transpiring surface often without a proportional increase in absorbing roots.

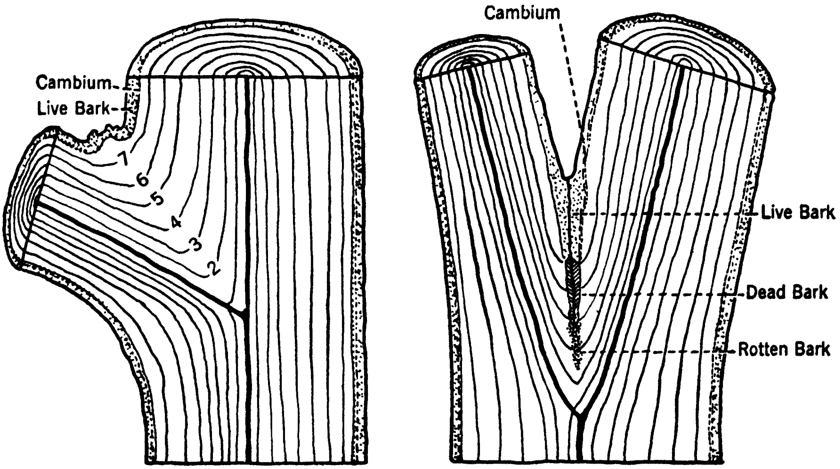
On the other hand, when excessive pruning reduces the leaf function (shading effects) and at the same time results in excessive shoot growth, it will eventually bring about a lowered water supply because of an indirect reduction of root growth. This result involves a period of time and in regions where the growing season is quite long, this effect is somewhat moderated in view of the longer period of photosynthetic activity.

Production of a Strong Crotch

One of the most important objectives in training a tree is to obtain a framework that is mechanically strong and not subject to breakage at the main crotches. The two essentials of a strong union of branches forming a crotch are: (1) inequality in the diameter of the two branches and (2) the wide angle between the two components.[39, 52]

Unequal diameter of the two branches. Breaking tests in New York clearly indicated that, other conditions being equal, the crotch is stronger if the branches are of unequal diameter. This is due, in part, to the fact that the wood and bark of the larger branch forms a supporting socket extending around the lower portion and sides of the smaller branch where the two are joined.

Width of angle. An acute angle between two branches is, in general, weaker than a wide angle. This weakness results from the bark inclusions which frequently separate the wood of the two components of the crotch. (Fig. 48.) An overly acute angle may still be relatively strong, provided there are no bark inclusions.



(Courtesy Ohio Agr. Coll. Ext. Service.)

FIG. 48. Wide strong crotch (left) and narrow weak crotch (right). Note relative thickness of the seven successive annual layers of wood (numbered) laid down by the cambium in the crotch angle. Also note cleavage line in bark of weak crotch indicating bark inclusions.

Orchard observations indicate that the different varieties of all tree fruits show considerable difference in the width of the angle produced. The Northern Spy apple is characterized by narrow angles and the Rhode Island Greening by a wide-angled crotch. These natural differences between varieties are more pronounced than those induced by training. This natural width of angle is an important factor in adapting methods of training to the purpose at hand.

Tree Bracing

Tree bracing is a means of reinforcing weak crotches in order to prevent breakage.[40] The practice is particularly advisable in the following cases: branches of equal diameter showing bark inclusions; where there are winter-injured crotches; with older trees in which the crotches are weakened by large pruning wounds. Tree bracing was particularly necessary when the open or vase-shaped trees were grown, but it is less imperative since the advent of the modified leader. Intertwining branches may be utilized as a living brace, or suckers may be similarly inarched into larger branches. On the other hand, artificial braces consisting of wire loops fastening into screw eyes are more common. Living braces should not be instituted when the tree is very young or the spread of the branches will be prevented as the trees come into heavy bearing.

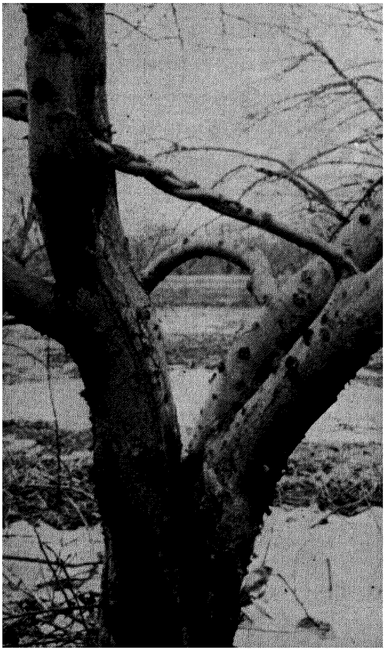


FIG. 49. Natural braces which strengthen weak crotches.

MacDaniels has outlined a procedure for artificial braces.[40] For trees under 10 years of age a vigorous shoot may be satisfactorily inarched to a large branch, thus forming a natural brace. (Fig. 49.) For trees under 20 years wire loops with screw eyes are also satisfactory but the screw must not be placed in wood less than 3 inches in diameter or breakage will result. For older trees, ring bolts in place of screw eyes, and No. 8 or 9 galvanized wire, are recommended.

Methods of Making Pruning Cuts

The procedure in making pruning cuts varies in accordance with the size of the limb to be removed. The limb should be severed so that no stub is left to decay and carry disease organisms to the main branch. Furthermore, the cut should not penetrate the remaining branch so as to leave a wound of greater diameter than that of the portion removed. Frequently, there is a slight bulge around the base of the limb. The cut should be made so as to expose a wound of the smallest diameter and therefore should begin close to the bulge and should continue through the wood in such a direction as to come out adjacent to the bulge below.

In the case of a medium to large limb which may strip the bark when it falls, a preparatory undercut is first made about 8 to 10 inches out from the base of the limb. The next cut starts from above, 2 or 3 inches nearer the base than the first cut. The limb will then fall without damage to the bark and the short stub can be removed easily and cleanly.

Treating Pruning Wounds

The vigor of the tree and its consequent stimulation of callus formation affects the healing capacity of pruning wounds. The season at which the operation is carried out is also pertinent. Wounds produced in 6 species of trees from February 15 to May 15 developed a more favorable callus than similar wounds at any other time. In addition, wounds upon the trunk or lower branches and those close to the axis of the stem also heal more rapidly. Collins gives directions for the treatment and care of wounds to which those interested should refer.[15]

Pruning wounds in fruit trees have never been systematically treated. This is partly due to the fact that untreated wounds have shown a remarkable recovery and, furthermore, no ideal wound dressing was available. A satisfactory wound dressing should possess the following characteristics:

1. It should cause little or no injury to the cambium.
2. It should be elastic enough to bridge the weather checks which frequently develop on both large and small wounds.
3. It should adhere well when the wounds are fresh.
4. It should be reasonably durable.
5. It should be pliable under changes in temperature.
6. It should prevent the entrance of disease or rot organisms into the wound.
7. The material should be dark in color.

Wounds of less than 2 inches are usually left without treatment, since, if the cut is properly made it heals rapidly. Larger wounds have been treated with various disinfectants and dressings and with varying success. Some treatments proved to be fairly successful, others definitely harmful.

Many materials have been recommended and used as dressings; common paint, white lead, linseed oil (with lamp black to darken), grafting wax, coal tar and asphalt compounds are perhaps most commonly used. Bordeaux paste prepared by stirring Bordeaux powder into raw linseed oil until a paste-like consistency is obtained has been used as a disinfectant. This material, however, is not durable. Common paints are not satisfactory except for small wounds since the wound may check and the turpentine kills the exposed cells. Grafting wax has a tendency to crack and peel away from the wound. Coal tars have been frequently found to injure the cambium. Recently several asphaltum compounds have been found quite satisfactory, and now tree surgeons and investigators conclude that the best wound dressings possess an asphalt base and contain no injurious liquids such as benzene and gasoline.[40] After wounds start to heal the wound dressing should be prevented from touching the callus or its growth may be restricted. In some instances, wounds have been disinfected with a solution of 1 to 1,000 mercuric chloride (corrosive sublimate) followed by an asphalt wound dressing.

Wounds on winter-injured trees. Treatment of wounds on winter-injured wood offers a special problem. The vigor of the tree or branch has been impaired and natural healing is, in consequence, very slow. The heart wood presents an excellent medium for fungi and bacteria. MacDaniels [41] writes, "up to date we have not found anything that is of much value on winter-injured wood. If applied to dry wounds, the water soluble asphalts seem to be the best as regards their durability and lack of toxicity." He further recommends that the application of a wound dressing in the apple should be delayed until after gum formation has taken place and healing has started. This would occur in New York in the July and August following winter pruning.

Disposal of Brush

Brush rake and burner. Two of the most convenient devices recently used to facilitate the disposal of brush and trash in the orchard are the tractor brush rake and the portable brush burner.

A tractor brush rake may be operated wherever there is room between the trees and the ground is fairly level. With this implement the brush is collected in front of the tractor and pushed to convenient burning stations. (Fig. 50.)

The brush burner consists essentially of a large metal container mounted on skids or low wheels so that it may be drawn about in the orchard by a team or tractor. A discarded metal dump-truck body that is not too heavy may be easily converted into a suitable brush burner. A fire is built in the metal bed and the brush is picked up and thrown directly on the fire.

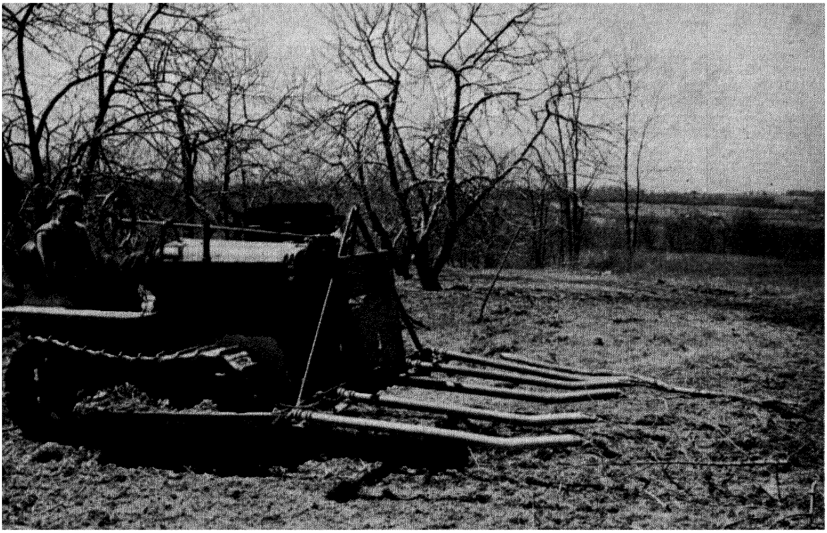


FIG. 50. Tractor brush rake in use in an Eastern orchard.

Time and Season of Pruning

The dormant season, that interval between leaf fall and the opening of the buds in the spring, has been the preferable period for pruning. This is true not merely in respect to the operation itself, but because it can be more easily adapted to labor distribution at this time. Summer pruning is discouraged for reasons already discussed. Trees are not barked easily when dormant, and, furthermore, the worker can more easily observe the relationship of the branches. Consequently pruning in the northern United States has usually been done in mild days in December, January, and early February. However, the question of winter injury is involved in the problem of dormant pruning and is discussed elsewhere. It is evident that fall or winter pruning of fruit trees may become quite hazardous in case low temperatures are experienced in the months following. For this reason pruning should be delayed until the probability of extremely low temperatures is past.

Forms Used in Training Fruit Trees

The principal object in training a young tree is the development of a strong framework of scaffold limbs. All systems or methods of training must stand or fall by their ability to achieve a tree capable of bearing high yields of fruit without undue breakage. Furthermore, since even a light pruning tends, at best, to lengthen the period from planting to flowering, the system used should involve the removal of as little wood as possible. Thus, in order to reduce pruning to a minimum the method must take account of the natural growth habit since varieties differ considerably in this respect.

In the past several forms have been used in American orchards. Each possesses advantages and disadvantages, but time and circumstances have altered the idea of the essentials of an acceptable form. As a matter of fact, no one method is ideal but at present the preferable form for most tree fruits is termed the "modified leader." The "vase" form, also called the "open head" or "open center," is more commonly used for the peach and apricot, but even the peach may be trained to the modified leader with very satisfactory results. The other forms, known as "two story" and "central leader" were occasionally used in the past but now have practically no adherents, and are entirely discarded except where they develop fortuitously.

The modified leader. Preference for the modified-leader tree depends upon the fact that it combines more of the advantages and less of the disadvantages than any other system of training. The modified leader derives its name from the fact that, during the first few years following planting, a leader or dominant branch is developed, which is eventually modified or suppressed when the other scaffold limbs have been properly established.

The outstanding advantage of this form is the fact that it possesses stronger crotches than the vase-form or open-head tree. The stronger crotch is the result of the disproportionate growth of laterals which is temporarily encouraged, thereby strengthening the framework at the point at which the laterals develop from the main axis. Furthermore, the diverging laterals are spaced at wider intervals along the trunk which as the form develops, is taller than that of the open-head tree. Usually this type of training produces about the same number of scaffold branches, and the resultant angles are probably no wider than those of the vase-formed tree, but, as above indicated, the chief advantage lies in the increased strength achieved by scaffold branches of *unequal* diameter arising from a central axis.

Pruning to this form first involves the selection of a "leader" or dominant lateral which is encouraged to exceed the growth of the other laterals during the first few growing seasons. This leader is usually situated at (or near) the terminus of the trunk since branches in this position normally tend to grow more vigorously. In fact, the production of a leader from a lower lateral would involve suppressing the growth of laterals situated above the leader to a considerable degree.

The ideal development of the modified leader requires that the growth of other laterals, as well as the leader, shall be disproportionate. To produce this condition the laterals designed for scaffold branches are cut to unequal lengths, thus inducing a disproportionate leaf surface and an unequal diameter of the branches. This condition is not always perfectly attained, but the framework is inevitably strengthened by this procedure. Sometimes the one selected as a leader fails to develop properly and it may be wise to substitute another for it during the first two or three years.

The modified-leader form involves the selection of laterals which will allow the greatest vertical distance between the branches arising from the main axis of the tree. In the open-head or vase-form the laterals branching from the main axis are much more closely spaced along the trunk since the severe heading back of the 1-year-old tree, induces the growth of closely adjacent buds at the terminus of the stem. This result is always apparent in the open-head training of the peach, which, at planting, is headed back to the conventional 24 inches. On the other hand, when the modified leader form is used, larger trees should be purchased from the nursery and the laterals are spaced along a greater distance on the main stem.

Usually the leader is not suppressed until after the other laterals have become well established. A leader should not be suppressed too soon, or the other laterals making up the primary scaffold limbs may equal its size and growth, thus resulting in what practically amounts to the vase-form. The leader is usually modified after about five years in the case of the apple; less time is required with the peach. Not infrequently this development takes place naturally without any special cutting of the leader.

As the laterals that branch from the main axis develop, they, in turn, will also branch, and in this manner a secondary framework is developed, which, in a mature tree, may comprise 8 to 10 large scaffold branches. Too many of these secondary scaffold limbs give rise to unwarranted crowding; no more than two secondary laterals should be allowed to develop from any one primary arising from the main axis.

One of the chief objections to this form except in the peach is that the growth of the leader may become too widespread or tall in proportion to the other scaffold branches and thus unduly crowd them. This tendency is inherent in certain varieties and may be prevented by the timely suppression of the leader and by the appropriate thinning out of some of its small branches.

Vase-form, open-center, or open-head. As the name indicates this form involves the development of diverging branches, approximately *equal* in diameter at their base, which, with their open-center, present a more or less vase-like appearance. In order to achieve this form with the apple or the peach it usually becomes necessary to suppress the growth of the uppermost branches after the second year's growth. As far as possible an equal leaf surface is maintained on the laterals which comprise the main scaffold branches, and the tendency of one to outdistance the other is promptly suppressed.

The advantage of this form is its broad, rather spreading shape. In addition, the open-center facilitates various operations, such as spraying, thinning, and picking.

The main disadvantage is a tendency toward structurally weak crotches, a condition resulting from scaffold limbs of equal diameter. Furthermore, the branches are apt to be rather closely spaced along the trunk or main axis. Such an undesirable development is not necessary since a greater distance can be maintained if special attention is given to that point, but the usual vase-formed tree has been characterized by scaffold branches of more-or-less equal diameter crowded around a common point on the trunk, a situation obviously in need of remedy.

A specialized form of pruning, termed "clover-leaf" because of its resemblance to a four-leaf clover, requires only that four primary scaffold branches be developed. Each one is maintained as a distinct wedge-shaped unit throughout the life of the tree.

PRUNING SPECIFIC FRUITS

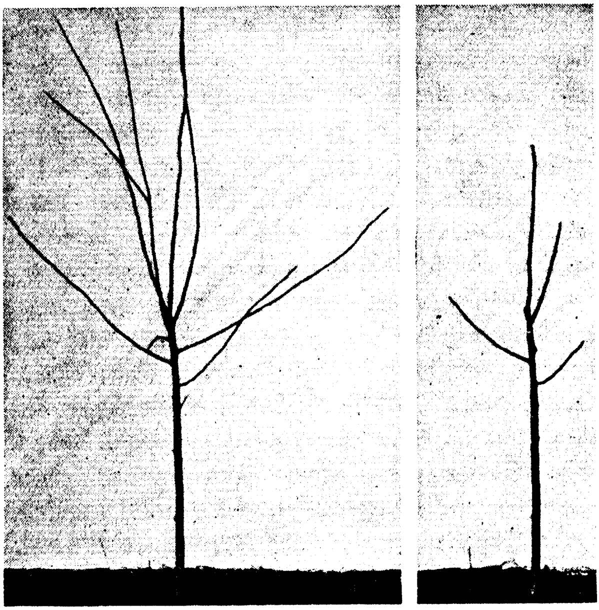
The Apple

One-year-old tree. For training to the modified-leader form, 1-year-old trees preferably of the largest size ($\frac{11}{16}$ inch in diameter and 5 to 7 feet tall), should be purchased. This will permit heading back to the 36- to 48-inch height, thus allowing for a greater vertical distance between the laterals forming the main scaffold limbs. Furthermore, a tree headed to 48 inches will still allow for the removal of the slender upper portion, thus leaving large, well-matured buds capable of a strong lateral growth. Following this heading back, all laterals which develop are usually allowed to grow throughout the current season, the selection of permanent laterals being delayed until the beginning of the second growing season.

Within recent years another procedure designed to develop the modified-leader form has been used experimentally and, in a limited way, commercially with 1-year-old trees. This procedure is called *deshooting* and involves the selection during the first growing season in the orchard of those laterals which are to form the primary scaffold branches, and the elimination of those undesirably placed. Only the largest-sized 1-year-old trees, headed back to 48 inches are adapted to this procedure. All the buds are allowed to develop into shoots but, after 3 or 4 weeks' growth, all shoots except those intended for the permanent framework are removed. The selected shoots should be well spaced up and down and around the axis and no one should be situated directly below another. From 3 to 5 shoots (preferably no more than 4) should be allowed to develop. The upper one, which normally achieves the greatest growth, is specified as the leader.

The earlier experimental work, of which deshooting is an outgrowth, involved the removal, when dormant, of all buds except those designed to form the main scaffold branches. This procedure which is known as *disbudding*,[21] has never been generally accepted. For one reason, narrow angles tend to develop in response to this treatment. Furthermore, single disbudding (the retention of only one bud at the desired location) was unsuccessful because of the unexpected destruction of buds, thus resulting in an ill-formed tree.

Disbudding which removed all but one bud in the region of a prospective lateral reduced the competition between shoots, and thus resulted in the more vertical, narrow-angled laterals characteristic of decreased competition. For this reason attempts have been made to eliminate this disadvantage and to adapt the principle involved in disbudding to the training of the modified-leader tree.[7, 52] Investigators allowed 2 or 3 adjacent buds to develop into shoots at each selected locus. This procedure called "group disbudding" has resulted in considerable improvement in the width of the angle. It is generally conceded that no shoots should be removed until a few weeks after bud break, thus allowing a sufficient period of competition after which growth may be concentrated in the laterals designed to form the primary scaffold system.



(Courtesy Ohio Agr. Ext. Service.)

FIG. 51. Left, two-year-old apple tree after planting. Right, same tree after pruning. The laterals have been thinned down to four, one dominant and three others cut back to disproportionate lengths.

Two-year-old tree. In cases where 2-year-old trees are purchased, the first step in training is the selection of laterals for the scaffold limbs. Such trees have usually been cut to whips about 36 inches long after 1 year's growth, and have produced a number of laterals, two or three of which are usually quite satisfactory for developing the framework. The selected laterals should be those most favorably located around the main stem. The largest lateral, usually occurring near the upper end, is left as the leader but is cut back beyond the willowy, immature portion at the tip. Two to four, preferably no more than three laterals, are also selected to occupy the various sectors. No laterals should be allowed to remain directly below the leader. It is sometimes considered preferable to leave only two laterals in addition to the leader at the time of pruning, and to select as the additional one, a later offshoot of the leader. The laterals are then cut back to disproportionate lengths in order to induce unequal growth. In addition, they must be shortened as compared with the length of the leader. (Fig. 51.)

If the 1-year tree was deshooted during its first growing season in the orchard, the laterals will have been selected and little or no pruning may be necessary. However, if other laterals have achieved a growth equal to the leader, they should be headed back in order to maintain their disproportionate length during the succeeding season.

Three- and four-year-old trees. The pruning adapted to the 3- and 4-year-old trees is primarily designed to maintain the proper relationship between the branches which make up the scaffold system. The dominance of the leader must not be sacrificed and any lateral which may have formed a V-shaped angle with the leader should be eliminated. In general, the laterals should maintain somewhat the same relative position during the third growing season that they occupied previously. The laterals left at the end of the second season's growth will branch during this year and form new laterals, one or two of which diverging from each primary lateral will comprise the secondary scaffold framework. It is frequently desirable to develop a rather large secondary lateral from the leader. This lateral will be comparable in size to the laterals developing from the main axis below the leader. Laterals from the leader often have good crotches, a fact which must be taken into consideration at the beginning of the fourth growing season.

In both the 3- and 4-year-old tree all water sprouts should be removed, as well as any twigs, which, by their growth during the following season, will interfere with the legitimate development of others. Small branches which may crowd those more desirably located should be thinned out or suppressed. Apart from the necessary cuts, as aforementioned, no wood should be removed; the "tipping" of twigs is particularly to be avoided.

Five-year-old tree. If at this time the main scaffold branches are satisfactorily established, the leader may now be cut back to a well-placed, outward-growing lateral. Otherwise, the pruning is similar to that of the previous year.

Further pruning of young nonbearing trees. In the subsequent years previous to bearing the light, corrective type of pruning should be annually continued. Water sprouts and dead and diseased wood may of course be removed at any time. But even though the tree appears quite dense, only those branches interfering with essential portions of the framework, or those diverging at a sharp angle should be removed or suppressed during this period. In case of doubt it is better to leave the branch. Where branches are closely parallel, one or more should be removed. If two limbs are concerned, the weaker of the two or the one less desirably located should be removed. No double leaders or "whorls" should be allowed to develop.

Pruning young bearing trees. Pruning the young bearing tree involves very little removal of wood until the extent to which the tree is opened by bearing has become evident. The annual corrective type is preferable, and if the trees have been properly trained no large cuts should be necessary. The extent of the thinning-out pruning depends in large part on the quality of the fruit to be produced.

It should be emphasized, finally, that trees during their first bearing years are not in need of reinvigoration. Satisfactory growth should be maintained by other practices, such as proper soil management, adequate fertilization with nitrogen-carrying fertilizers, and a sufficient water supply. Certainly one should not judge the value of the day's work by the amount of brush in the orchard.

Pruning the older bearing tree. Investigation seems to have concerned itself much more thoroughly with the pruning of nonbearing or young, bearing trees than with the bearing orchard. Relatively little data are available in relation to the pruning of trees over 15 years of age. In general, both the amount and type of pruning is found to differ considerably throughout the various fruit-growing regions of this country. Even in individual orchards within a single region the practice is not uniform, a situation due not only to factors concerned with the age of the bearing trees and their planting distance, but also to the size and quality of the fruits required. In view of this latter aspect economic conditions are also important in regulating the pruning advisable for older, bearing trees.

In general, it may be said that a rather pronounced tendency toward lighter pruning of bearing apple trees has developed in the East.[20, 42, 44, 49] In Michigan the experiments indicate the desirability of a light to moderate pruning. It is observed that a moderate pruning is followed by less fruit thinning, whereas a light pruning practice tends to emphasize thinning. There is general agreement, however, that pruning must be definitely and closely related to the size of the yield and the net return. This entails the production of a vigorous tree with a large bearing surface. In addition, it must be sufficiently open to permit effective spraying and satisfactory control of insect pests and plant diseases.

The tendency toward a lighter pruning of bearing apple trees has been occasioned by a lower premium in certain localities for fruit of the larger sizes and better color. Conversely, where a greater premium is paid for size and color, moderate pruning is still the established practice. It is undoubtedly true that in some cases pruning is insufficient to permit effective spraying. If the fruits are small, limb-rubbed, and poorly colored, a moderate removal of small branches may be necessary, followed by a lighter pruning thereafter.

Examination of the fruit both before and after harvest will indicate whether or not the current pruning is producing the desired result. In general, the pruning of trees which have been bearing for some years should not involve the removal of large limbs. Bulk pruning (large cuts) may occasionally improve the framework, but this type of pruning will usually, if not invariably, reduce the yield considerably. The cuts, which, as far as possible, remove only small branches, well distributed throughout the tree, are more likely to obtain the favorable effects of pruning and at the same time to incur fewer disadvantages.

Within the last few years the term "thin wood" pruning has been applied to a lighter practice.[49] This type of pruning involves the removal of wood which is small in diameter for its age and which develops poorly colored fruit, of small size, or is even barren. This thin wood results in all probability from the effects of shading or competition, namely, carbohydrate deficiency, and should be removed by means of numerous small cuts throughout the innermost portions of the tree or wherever it may be located in the periphery. Michigan investigations emphasize the removal of the relatively unproductive thin wood from the innermost portions of the tree. As a result of this operation the proportion of culls in the final yield is considerably reduced and the harvested crop is restricted to the portions of the tree from which a high proportion of the fruits will be of good size, color, and of a satisfactory quality. Any underlying branches, large or small, which develop close to the ground and tend to produce culls, are removed also. In practice, it is evident that many cuts of this nature can be made quite rapidly with the lopping shears.

Interfering branches and those growing too closely parallel must receive attention. In addition water sprouts and diseased and cankered wood may be removed at any time. Water sprouts, however, may occasionally be used to form a branch in a desired sector of the tree.

Branches which too greatly extend the height of the tree should be headed back to a desirably placed lateral, but it may prove advisable to extend this process over 2 or 3 years. Twenty feet is usually the maximum height to which a tree should be permitted to grow.

In the Pacific Northwest pruning has been rather heavy, judged by Eastern standards. Recently a tendency toward even greater severity has developed [45] due to the fact that the trees which are rather closely planted, have now begun to crowd each other with considerable overlapping of branches. As a result the growers are pruning more than formerly in order to suppress crowding and maintain satisfactory shoot growth.

Reinvigoration of old trees. If the tendency which is developing to remove trees at an earlier age than formerly continues, the special problem of handling old trees will be removed in many commercial orchards. The problems of maintaining size of fruit and of economical production have caused growers to consider the replacement of apples, in particular, after 30 to 35 years. The economics of this is yet to be worked out. It would seem reasonable that the reinvigoration of mature trees should, under no circumstances, be attempted unless the varieties are good, the trees not too old and showing good crotches, and a large bearing surface occurs within a reasonable distance of the ground. It should not be necessary to use ladders over 20 to 22 feet in length, otherwise thinning and picking become too difficult.

If the trees satisfy the above conditions they should be cut back, if too high, to side laterals. Small branches should be thinned throughout the tree, although large branches may occasionally have to be removed.

Pruning as related to fillers and planting distance. Filler trees until they come into bearing, should be pruned as lightly as possible, in order to hasten fruitfulness. They may then be pruned as are the permanent trees. Whenever they begin to crowd the permanent trees or to interfere with orchard operations, the branches which spread horizontally, or are too tall, may be "fanned" or cut back to laterals. This may involve a rather heavy pruning but the fruit, though somewhat reduced in quantity, will be of good quality. By this means many filler trees have been utilized from 8 to 10 years after they have come into bearing. Occasionally even the larger branches may be thinned. These fillers, however, must on no account be left so long as to seriously injure the permanent trees.

The Pear

The modified leader is generally conceded to be well adapted to the pear. The pruning procedure in this case is similar to that prescribed for young apple trees. Deshooting the 1-year-old tree has been recommended in preference to heading back and thus allowing all shoots to develop throughout the subsequent growing season.[36] If the more conventional method is used, the 1-year-old whip is headed back to 36 to 48 inches; if deshooting is to be practiced the whip should be headed to 40 to 48 inches, preferably the latter. Agreement seems to be general that 4 to 6 main lateral branches should be allowed to develop from the trunk in order to minimize the proportion of loss which may occur as a result of fire blight infection.

The pruning of the young, nonbearing tree is similar to that of the apple, and only a minimum of wood should be removed. Particular attention should be given to developing strong crotches. The pruning is at a minimum as the tree comes into bearing. Care should be taken that limbs or branches are not removed merely because the tree appears to be too dense, for bearing spreads the tree considerably.

Pear varieties have been separated into two categories based largely on their bearing habit.[36] Group 1 includes Beurré Hardy, Beurré Bosc, Beurré Clairgeau, Lawson, and Flemish Beauty, all of which are characterized by a strong tendency to develop spurs which contribute very little new growth. Bearing occurs largely upon these spurs, and any new growth occurs chiefly at the point of pruning. The second group, consisting of Bartlett, Easter Beurré, Winter Nelis, and Patrick Barry, shows a vigorous spur and shoot growth throughout the tree. According to this characterization it is recommended in the Pacific Coast states that the varieties of group 1 should receive a moderately heavy, detailed pruning in order to maintain an abundant flower formation. It is also considered essential to head back a number of branches and twigs and to thin out branches and spurs that have been fruiting for some time. On the other hand, it is recommended that the varieties of Group 2 should be pruned very lightly.

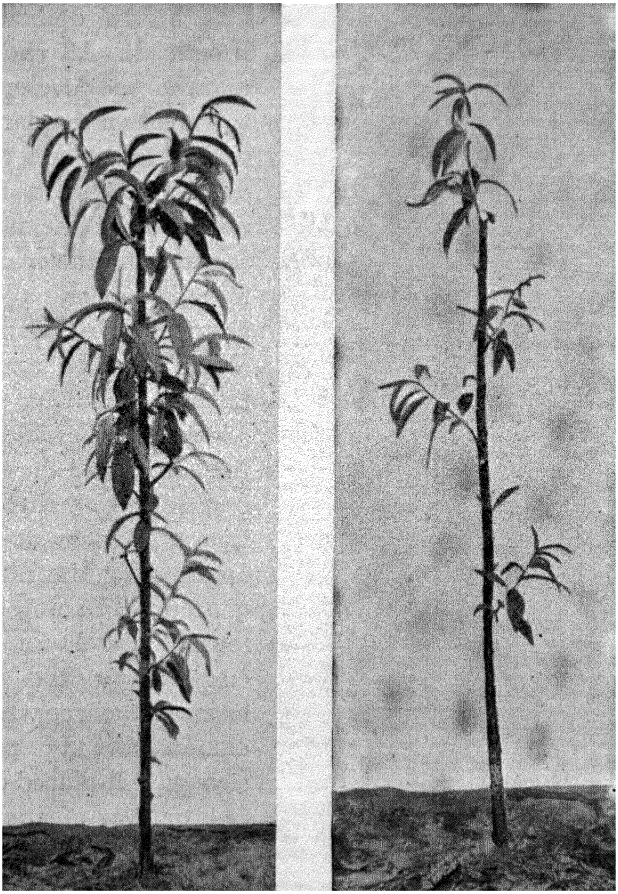
The objection to the procedure in regard to the varieties of the first group is that it seriously increases their susceptibility to fire blight (*Bacillus amylovorus*). It would seem advisable under Eastern conditions that the bearing trees of all varieties be given very little pruning in order to maintain a slower, harder growth. In the case of young bearing trees this does not even necessitate annual pruning. Branches and twigs that rub or cross badly may be removed, but the diameter of the cuts should be as small as possible. Furthermore, there is no justifiable reason for heading back terminal twigs at the top of the tree—a procedure which produces a bushy growth and greatly reduces the yield. Occasionally a tree may become too tall, thus requiring a light heading back.

It is advisable to remove spurs and twigs which are likely to flower, for a distance of at least 18 inches at the base of the main scaffold limbs. Otherwise these may become infected with fire blight, and, before the disease is recognized, it may spread quickly, thus girdling the tree. Wherever water sprouts occur, they should be removed also.

During winter pruning and before growth starts, a search should be made for blight cankers, so that they may be removed at the time when the organisms causing the disease are dormant. One should also examine the tips of the long terminal growth of the previous season for blight. Blighted shoots retain their leaves through the winter and are thus easily recognized. Beginning shortly after bloom the trees should be inspected every 2 or 3 days for shoots and spurs infected with blight. Prompt removal of the diseased portions, together with careful disinfection of the wounds seems at present to be the best means of reducing the number of large branches which must be removed.

The Peach

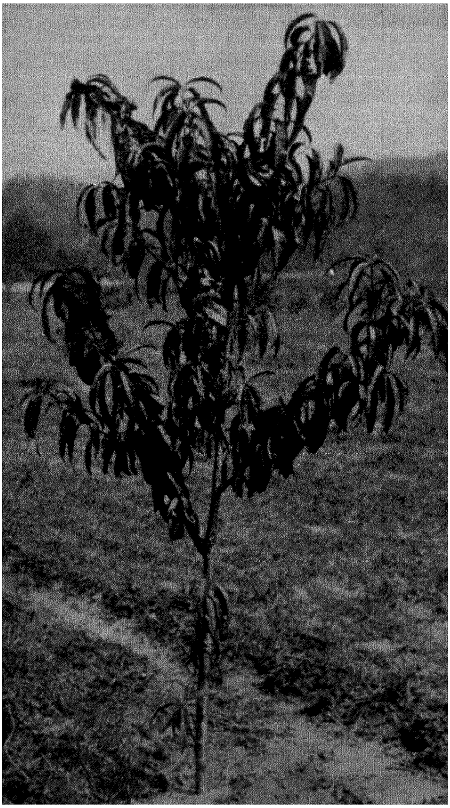
Although the peach has usually been trained to the open head or vase-form, the modified leader has recently proved so satisfactory that it now seems preferable, at least with most varieties. Furthermore, deshooting has been shown to produce trees with such excellent, wide-angled crotches that this method of training the young trees has gained preference over the more conventional method.[17, 53]



(Courtesy Frank P. Cullinan, U. S. Hort. Research Center, Beltsville, Maryland.)

FIG. 52. One-year-old peach tree before (left) and after (right) deshooting.

One-year-old tree. Modified leader by means of deshooting. For training trees by deshooting, large vigorous trees, no less than $\frac{9}{16}$ inch in diameter and preferably $\frac{11}{16}$, are required. They should be of sufficient length to permit heading back to 48 inches. Where "June buds" are used they must be cut back and allowed to develop a long vigorous axis before deshooting is practiced. All shoots are allowed to develop for 3 to 4 weeks after planting at which time 4 or 5 that are well spaced up and down and around the axis, are selected for the main scaffold branches, all other shoots being removed. (Fig. 52.) The uppermost lateral, occurring at the 48-inch level, will become the leader and the remaining laterals should be spaced at least 6 inches apart along the main axis or stem. In case of 5, the lowest lateral should occupy about the 16-inch level. If the tree when purchased already possesses strong, well-placed laterals, one or two of these may be left, with little heading back, to develop main scaffold branches. A tree both before and after deshooting, and at the end of the first season following, is shown in Figs. 52 and 53.



(Courtesy Frank P. Cullinan, U. S. Hort. Research Center, Beltsville, Maryland.)

FIG. 53. Peach tree at end of season following deshooting showing excellent growth of selected laterals.

"Open-head" training. According to the conventional "open-head" form, the tree is headed back rather heavily at planting time, with the height of the remaining stem varying from 18 to 30 inches. Usually 3 to 5 well-spaced laterals are selected as the future main

scaffolds, and are headed back symmetrically to short stubs which have only one or two buds; all others are removed. (Fig. 54.) In case the nursery trees are too small, they may be merely headed back and left to develop a more vigorous axis.

In practice it has been found that there is a tendency to retain too many laterals, which, growing closely together, produce weak crotches and eventually break. This crowding is inevitable when a space of only about 12 inches intervenes between the lowest and uppermost laterals. Such a condition is frequently observed in these trees after pruning. Under such circumstances it seems advisable to retain at first, no more than 3 lateral stubs, thus depending upon the secondary growth from this main scaffold to form sufficient bearing surface for the tree.

Two-year-old tree. In the tree trained to the modified leader by deshooting, little pruning is done at the beginning of the second growing season. Any lateral which by its growth endangers the dominance of the leader should be headed back to an outward growing twig. Otherwise no "tipping" or heading back is advisable.

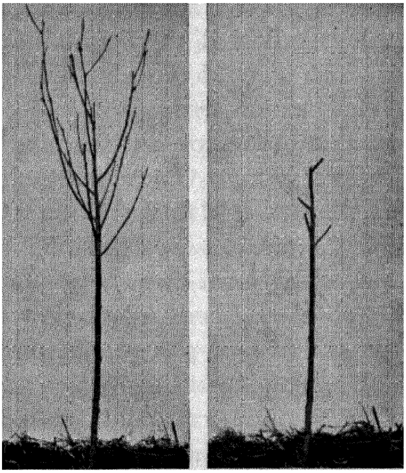


FIG. 54. One-year-old peach tree after planting (left); same tree after pruning, (right). The tree was cut back to about 24 inches. Four laterals were left and cut back to short stubs to assist in developing a symmetrical head.

In the conventional open-head tree all lateral scaffolds will usually have made a more or less equal growth. Where the relationship between laterals is such as to indicate possible dominance of one during the current season, the situation should be corrected by cutting back the dominant one to balance the tree. If the laterals have grown excessively long and tend to be somewhat "leggy," a light heading back to outward-growing twigs may be desirable. All twigs near the upper center and likely to grow too vigorously in an upward direction should be cut out, along with those twigs likely to cross the center of the tree. Twigs that are too close to the main stem on the lateral scaffolds should be cut off. The important point is that the laterals making up the main scaffold branches are not headed back as severely as was formerly the practice. In addition the scaffolds are stronger since they are further apart along the main stem.

It is not uncommon with the peach to find a strong shoot low on the tree growing so vigorously that the main body is decidedly dwarfed. One should not hesitate in such cases to remove the original portion of the tree just above the strong sprout and develop the tree from the latter, if better proportions will result. The angle so formed is quickly overgrown and the tree trunk will be straight.

Third growing season. The modified-leader tree requires relatively little pruning at the beginning of the third growing season. The original scaffold branches should by now have given rise to a secondary outgrowth and 1 to 3 of these laterals will be selected because of their superiority in size and position, to form the secondary scaffold system. Those selected may be lightly cut back to an outward growing lateral, but heavy heading back is not desirable. Other laterals, twigs, or small branches likely to interfere with the developing form must be removed. The dominance of the leader, if well established, might now be suppressed, and the growth directed to a well-placed, outward-growing lateral.

The pruning of the open-head tree is similar as far as the selection of the secondary scaffold system is concerned, except that particular attention must be accorded to the prevention of any "unbalance" or dominance of one main limb over the others. This may be prevented by heading back to outward growing laterals. Furthermore, a somewhat more decided thinning out of twigs and small branches is required in a tree thus trained, since the limbs diverging from the trunk at approximately the same horizontal level grow more-or-less equally, thereby tending to make the center quite dense.

Sucker-like shoots about the base of the primary scaffold should be removed, as well as those growing too vigorously upward through the center of the tree. In this tree as well as in the modified leader, the stronger twigs at the periphery of the tree should be lightly headed back to well-placed outward growing laterals.

The fourth growing season. Pruning at the beginning of the fourth growing season should be as light as possible, since moderate to heavy pruning at this time not only removes more flower buds, but prevents to a greater extent, the differentiation which would take place during the current season. Pruning at this time corresponds to the light thinning out previously characterized for the 3-year-old tree, except that a slight and carefully applied heading back at the periphery of the tree may be more essential. Since at this particular period, crowding at the center is characteristic, thinning out becomes necessary. In case the leader has not been modified, it may be done at this time, providing the other main scaffold branches are well established.

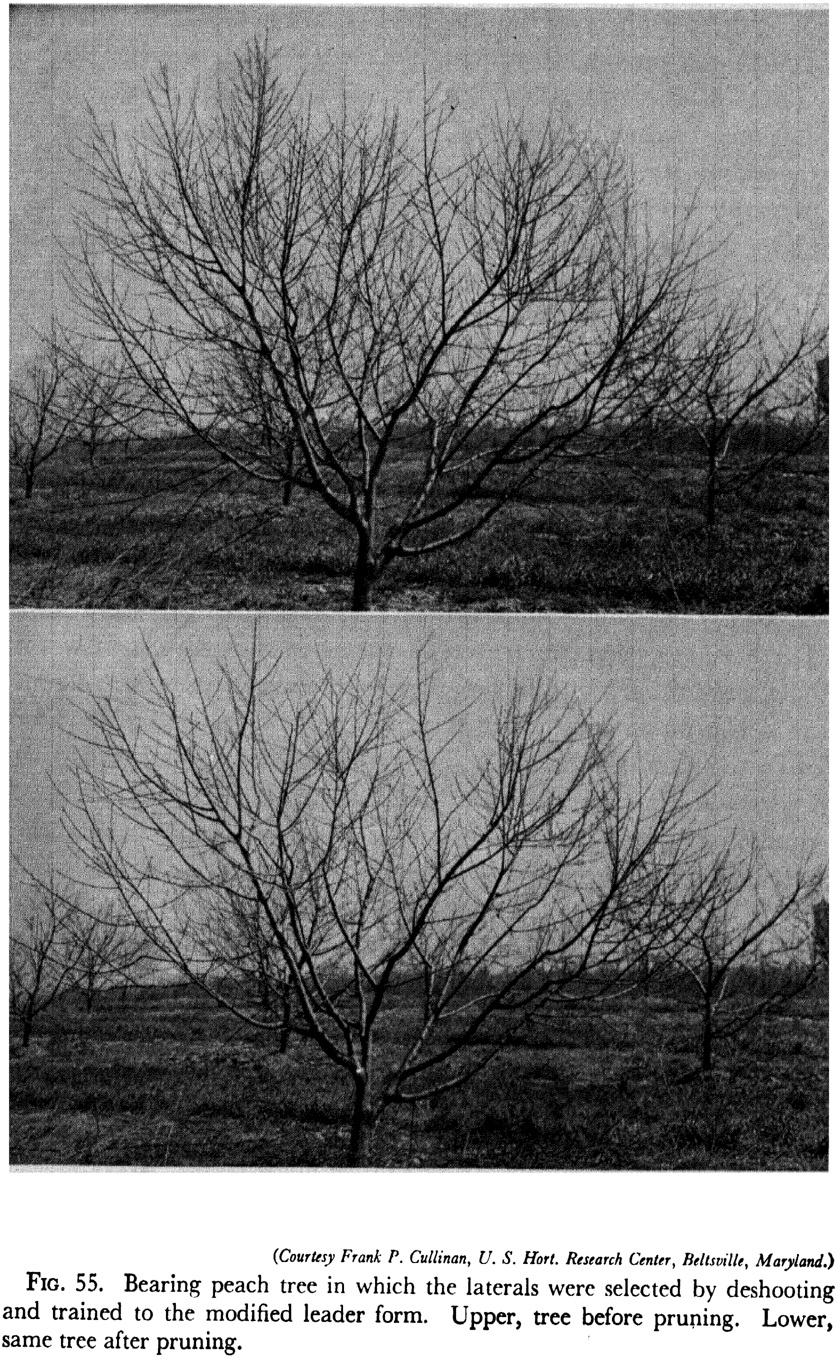
As noted in Fig. 55 the trees pruned to the modified-leader type, are not excessively high and yet they show a greater upward spread than the open-head trees. They also possess a very extensive bearing surface.[17]

Pruning the bearing tree. Well-grown trees seldom fail to produce enough flower buds for a heavy crop. Usually there are far too many, and pruning is therefore very helpful in thinning the crop as well as in providing conditions for proper renewal of fruiting wood throughout the tree.[24] It is important that bearing trees be pruned every year. Otherwise, the fruiting wood tends to develop farther out and higher up each year, and a thick-topped, "leggy" tree quickly develops.

Furthermore, the peach, which forms its flowers laterally on shoots, requires a vigorous length of new growth in order to produce a continuously satisfactory number of flower buds. It is for this reason that this fruit requires more pruning, relatively, than other tree fruits. The practice has always presented something of a problem, since it involves suppressing extreme height and at the same time encouraging a thoroughly adequate and well-distributed bearing surface.

This purpose is best accomplished by means of numerous small cuts which thin out the minor branches from a light to a moderate degree.[17, 24, 53] In addition a lateral rather than an upward growth is encouraged by heading back small, upright branches throughout the tree, in favor of outward-growing laterals. This is the type of pruning utilized by Cullinan in training modified-leader trees at the U. S. Horticultural Research Center at Beltsville, Maryland.[17] (Fig. 55.)

Rejuvenation of peach trees. "Dehorning" is no longer recognized as a means of rejuvenating peach trees devitalized by heavy bearing or neglect. Rejuvenation studies in Maryland found heavy or partial dehorning slow to produce results, while a moderately heavy pruning induced a more rapid rebuilding of the bearing surface



(Courtesy Frank P. Cullinan, U. S. Hort. Research Center, Beltsville, Maryland.)

FIG. 55. Bearing peach tree in which the laterals were selected by deshooting and trained to the modified leader form. Upper, tree before pruning. Lower, same tree after pruning.

and an increased yield.[64] The main branches and side limbs were headed back 4 to 6 feet, a process which removed 3- or 4-year-old wood and still left main branches from 6 to 8 feet in length. As usual the heading back maintained the outward growing laterals in preference to upright growth.

Following this operation only a moderate treatment was necessary during the next two seasons. Careful pruning which directs growth to vigorous laterals and keeps the bearing surface as low as possible without restricting yield, is advisable for rejuvenated trees.

Pruning after low temperature injury. Pruning should be delayed until no further danger of winter killing, either of buds or wood, exists. If no injury is apparent, the regular, well-distributed pruning may be immediately put into practice. Where a portion of the buds have been killed a very light pruning is advisable. Where the proportion is large the operation should be delayed until full bloom, when the extent of the injury can be determined. In case of severe injury to the wood, the trees should never be "dehorned" since the practice has been definitely shown to result in future mortality. In such cases, pruning should be delayed until late spring or early summer and the treatment at that time must be very light.

A period in which the buds are winter-killed may be an opportune time in which to renew the bearing surface of the tree. It is recommended in some instances that 3- or 4-year-old wood should be headed back, but the extent of the pruning must depend on individual circumstances.

The Sour Cherry

In spite of the fact that the sour cherry is known to be susceptible to crotch-splitting, laterals are often allowed to develop in close proximity to each other, and scaffold limbs have been permitted to attain the equalized growth that later induces splitting. In order to improve these detrimental conditions the modified-leader form, which can be achieved with a minimum of pruning, has now become preferable.

One-year-old tree. Vigorous 1-year-old trees at least 3 to 5 feet high can be developed most successfully. Quite often the laterals of 1-year-old trees are unsatisfactory, being short, weak, and immature. The procedure in such cases is not uniform, but it may seem advisable, following planting, to remove these weak, narrow-angled branches, a proceeding which may in some cases remove all.

Under these circumstances the leader also must be headed back to the mature wood in order to prevent too disproportionate a growth. On the other hand, a tall well-formed 1-year-old tree should be permitted to retain any wide-angled, well-located laterals.

The pruning involves the selection of the leader, and usually of no more than 3 other laterals, which should be distributed over 3 to 4 feet of the trunk above the lowest lateral. Limbs and scaffolds directly above, or opposite each other should be avoided in order to prevent girdling the leader—that is, diverting the direct line of nutritive materials. Those laterals which are to form the scaffold branches should be cut to disproportionate lengths as in the modified-leader apple and pear trees. The lowest lateral should be located about 15 inches above the ground on the southwest side. In some regions as in Missouri,[59] it is recommended that the laterals be left without tipping, because the lateral buds may fail to develop during the following season.

In general, however, laterals, other than the leader, should be headed back, and in case more than 3 are left at planting time, they should be removed after the first growing season in the orchard. In fact, the development of a large secondary scaffold limb branching from the main leader is preferable to a preponderance of primary laterals at the beginning. This selection of laterals may be continued through two seasons.

Pruning the nonflowering tree. During the subsequent years previous to flowering, pruning consists of a light, corrective thinning out.[50] Superfluous laterals which are likely to cause interference should be removed. No lateral must be allowed to girdle the main leader nor to make excessive growth. After several years, the leader itself should be suppressed.

Pruning mature trees. Annual pruning of the thinning-out type is required for mature, sour cherry trees. In order to secure high yields it is necessary to induce throughout the tree, the production of leaf buds which will develop into spurs. This result can best be obtained by a combination of light pruning and nitrogen fertilization.[23] By maintaining fruiting branches with many terminal growths of 12 inches or more, spur fruiting is encouraged and high yields induced.

As the tree matures an increasing amount of thinning out pruning is necessary in order to prevent the inside and lower fruiting wood from dying. In addition, branches which develop at odd angles and cross the tree must also be removed.

In the case of the Montmorency and Early Richmond varieties there is a tendency toward too tall a growth. This necessitates an occasional heading back to such laterals as extend more or less horizontally.

The Sweet Cherry

The modified leader form is also adaptable to the sweet cherry; the necessary procedure is similar to that already described for the apple and the pear. Since these trees are unusually susceptible to crotch splitting, special attention should be given to the development of a strong framework. Sturdy 1-year-old whips 4 to 6 feet, having a diameter of ¾ of an inch or more are recommended. The whips should be cut back only to about 48 inches. Development of the framework by the deshooting method as in the peach would seem the more desirable procedure. However, Havis at the Ohio Station has found that the shoots should not be removed until they have grown from 6 to 8 inches if wide crotches are to be obtained. Three to 4 laterals, not including the leader, are sufficient. They should be separated vertically by at least a foot and particular care should be taken to see that they are properly spaced around the main stem so as to prevent girdling the leader. Following the establishment of the framework the trees should be pruned very little until flowers are formed.

The sweet cherry has a tendency, particularly in the upright-growing varieties, to produce long, pole-like branches. This condition may develop in 3-year-old trees as well as after the trees come into bearing. Where this situation develops, special attention should be given to the problem of developing lateral branches. This can be done by heading back to laterals wherever possible, thus retaining the outward-growing twigs. This is particularly important with the varieties Lambert and Black Tartarian, which are characteristically even more upright than Napoleon. Light pruning should be followed throughout the life of the sweet cherry tree.

The Plum

The modified-leader form is recommended for the European, Japanese, and native species of the plum. Marked attention should be given to the development of strong crotches, particularly in the case of the Japanese plum which bears heavily.[61] The thinning out of undesirable branches and the prevention of excessive height, corresponds, in the case of the plum species and varieties, to the treatment already recommended for other fruits.

While the standard rules for pruning apply in general to the various species of the plum, there are a number of circumstances which condition the recommendations. Furthermore, the methods of pruning used in the East differ in certain respects from the practice of the West. In both cases the same *general principles* hold true, but should be adapted to the varieties in question as well as to the requirements of the immediate situation.

Certain varieties tend to grow upright, others to spread, and the pruning should be adjusted accordingly. For example, the Japanese varieties, such as Santa Rosa and Wickson, tend toward an upright growth and should be pruned to induce spreading, while other varieties, such as Burbank, are inclined to spread and should be pruned to encourage an upright growth. It is probable, however, that only within rather narrow limits can this be accomplished.

In the Pacific Coast states where plums and prunes are extensively grown, the final disposition of the fruit is a factor which partly determines the type of pruning.[29, 35] Trees designed to produce fresh fruit are usually kept lower than when dried prunes are required. Prunes may be shaken from the tree and thus the height is less important. Fruit which is to be marketed when fresh is also thinned more drastically. This is particularly true of the heavy-bearing Japanese varieties. In some cases where water is insufficient and the size of fruit is important, the terminals may be headed back, and pruning used more or less as a means of thinning the fruit. In such cases even the 1-year-old wood may be cut back.

Aside from these modifying circumstances the pruning recommendation for training young trees does not differ greatly from the pruning previously described. In the West 3 to 5 (preferably 3) laterals are developed as the scaffold, and at the dormant pruning following the first season's growth, they are headed back to about 15 to 30 inches from the point of attachment to the trunk, and developed according to the open-head form. This heading back induces the branching of the secondary scaffold. Undesirable shoots or water sprouts are of course removed. Subsequent pruning consists in thinning out the undesirable branches and the ordinary heading back of twigs and small branches to well-placed laterals.

The Apricot

The pruning of the apricot has received considerable attention in California where this fruit is extensively grown.[30] Although the pruning outlined below is followed in California, it is believed that under Eastern conditions, the modified leader would be preferable.

Contrary to most tree fruits, 1-year-old apricots are often received from the nursery already branched. Unfortunately, these laterals are not always properly spaced and so must be cut back, leaving short stubs with one or two buds at the base.

Apricot trees are usually grown with a relatively short trunk, the nursery tree being headed back to a height of 24 to 30 inches from the ground. During the subsequent growing season many lateral branches are formed. If early during this first summer a number of those less favorably located are pinched off, the growth of the more valuable laterals will be increased and the amount of dormant pruning required later will thus be reduced.

At the end of the first growing season in the orchard 3 lateral branches, separated by at least 6 to 8 inches, are chosen; all others are completely removed. These 3 laterals are then headed back to the height required for the secondary scaffold branches, which is approximately 4 or 5 feet from the ground. It is suggested also that they be cut back to disproportionate lengths in order to induce stronger crotches than would develop otherwise.

By the end of the second growing season numerous laterals have developed both from the scaffold branches and from the main stem. It is recommended that all but the permanent framework be removed as far up as the point at which the secondary scaffold is formed. Subsequently, pruning is essentially a normal thinning-out process. It should be just sufficient to keep the center of the tree open. Whorls should be eliminated, and a light heading back of laterals is occasionally practiced, but should be kept at a minimum until the tree comes into bearing.

Pruning the bearing tree should involve only a light to moderate thinning out of branches and some heading back to well-placed laterals. It is suggested that if the new growth is less than 15 to 30 inches a year, a more severe pruning may be necessary. Pruning should not reach the point of undue yield reduction.

The Grape

There are numerous methods of training Eastern grapes, a fact which increases the difficulty of presenting an orderly classification and description.

Disposition of shoots. In general, however, the bearing shoots may be disposed according to three positions: shoots upright, shoots drooping, and shoots horizontal.[25]

When the shoots are trained in an upright position, two or more canes are laid to the right or left, either horizontally, or obliquely along the trellis wires. As the shoots develop they are fastened to the wires above. Drooping shoots, as implied, are not tied but allowed to droop as they will. Although shoots may be trained horizontally, the one method, the Hudson horizontal, is now obsolete and need not be described.

These general training methods are again subdivided into a number of named systems, of which we shall discuss only the most important.[25] They are classified as follows:

I. Shoots upright
  1. Chautauqua
  2. Keuka High Renewal
  3. Fan (with certain modifications)

II. Shoots drooping
  1. Single-trunk four-cane Kniffin (and other modifications of the Kniffin system)
  2. Munson
  3. Upright or vertical (Muscadine Grapes)

The upright-shoot systems possess several advantages:

1. They are adapted to certain varieties such as Catawba which tend toward a short cane growth, and to such weak growing varieties as Delaware.
2. Short posts may be used for the trellis.

The advantages of the drooping-shoot systems are:

1. Summer tying of shoots is unnecessary.
2. Cultivation can be carried out without injury to the shoots.
3. Drooping foliage prevents sunscalding of the fruit clusters.
4. Better air circulation, more thorough spraying and easier harvesting result.
5. One less wire is usually required by the drooping systems.

The advantages of the drooping-shoot methods are in reality the disadvantages of the upright shoots.

In general, varieties differ in their adaptability to the two systems. The varieties Concord, Worden, and Niagara have produced more satisfactory yields when the shoots are allowed to droop.[25] On the other hand systems involving upright shoots are usually preferred for the varieties Catawba, Delaware, Diamond, and Moore Early. In Missouri[22] Moore Early was the only variety whose yields were as high with the High Renewal system as with the Kniffin.

In the United States the single-trunk, four-cane Kniffin (or occasionally a six-cane) is by far the most important commercially. In Maryland,[5] although the best yields were produced by the single-trunk Kniffin system, the Munson system proved to be nearly as productive, but it involves greater expense and is not commercially adopted. Experiments indicate that the various other modifications of the Kniffin, such as the two-trunk four-cane, or Y-trunk Kniffin have no outstanding advantages over the former method (single-trunk four-cane Kniffin) and do have disadvantages.[5, 22, 25] In New York the Chautauqua and Keuka High Renewal, and in Ohio the Modified Fan are used to a limited extent commercially.

Systems involving upright shoots. Chautauqua. In this system a trunk and 2 arms are established, from which the newly developed canes are tied in an obliquely upright position to the wires above. The trunk extends to just below the lower wire, and the arms are developed to right and left of the trunk. They should not, when established, extend for more than 3 feet in each direction along the lower wire. Each year 3 or 4 canes having 8 to 10 buds each are extended obliquely upright from these arms and tied to the upper wire (Fig. 56, upper). An equal number of renewal spurs are left as near as possible to the arms to furnish canes for the succeeding year. As they grow the developing shoots are tied in an upright position.

Establishment of the Chautauqua system. In order to develop this system in the young vineyard, a cane is brought up to the lower wire and cut off as soon as the vine is well established, which may be at the beginning of the second growing season in the vineyard. During the second season 2 shoots growing near the top of this main stem or trunk become the arms and at the beginning of the third growing season all canes but these are removed. A spur on each side of the main stem is sometimes allowed to remain but if so it is cut back to 1 or 2 buds. From these arms, shoots develop during the third growing season, from which a selection is made at the beginning of the fourth season. At this time 3 or 4 of these selected canes are tied obliquely to the wires above. Spurs are al-

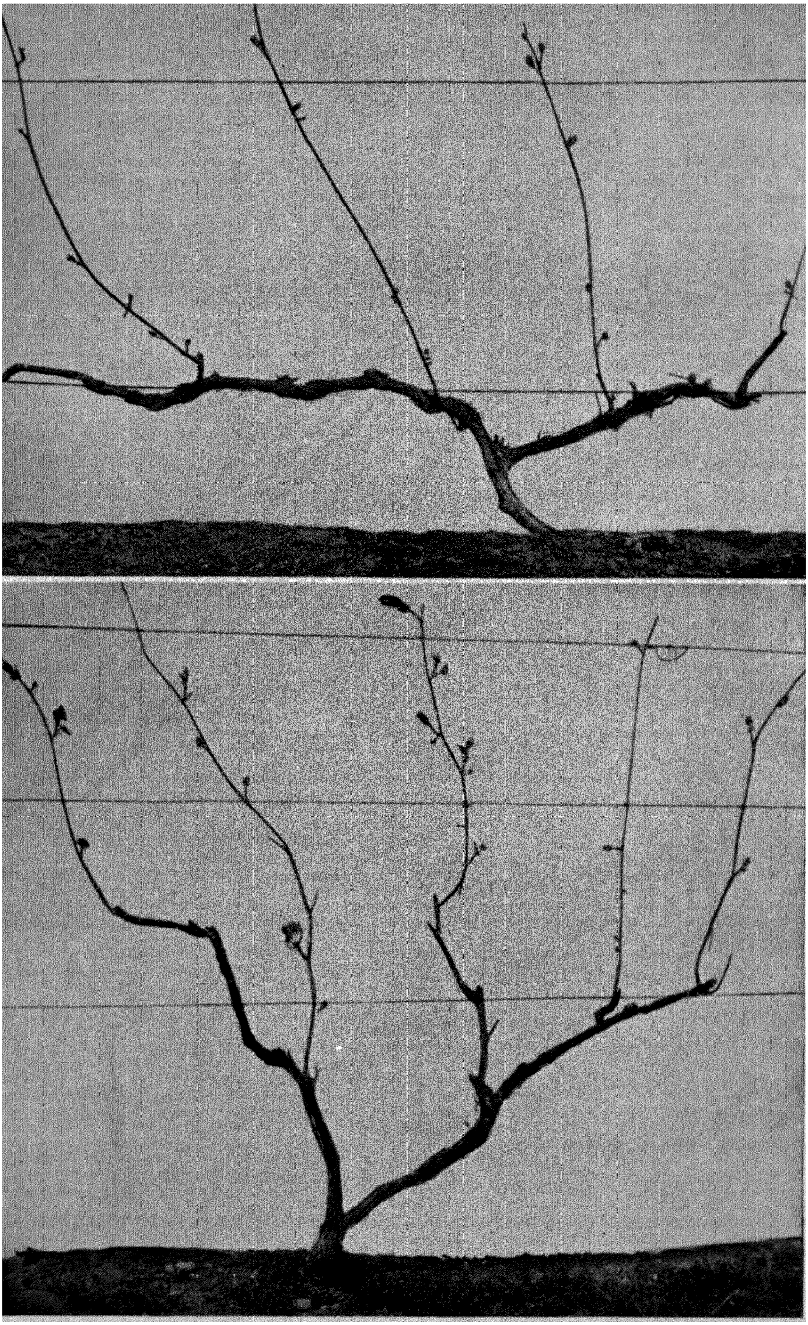


FIG. 56. Grape vines trained in accordance with the Chautauqua (upper) and Modified Fan (lower) systems.

lowed to remain in order to produce shoots near the head of the vine for the subsequent year's selection of canes to be tied obliquely to the upper wire.

If the vines are not sufficiently vigorous at the end of the first growing season, they should be cut back to 2 buds, thus delaying the formation of the arms for an additional year.

Two wires are commonly used but 3 are more desirable. The lowest wire is usually 18 to 20 inches from the ground and the second about 34 inches above the lower. When 3 wires are used the upper 2 are about 20 inches apart.

Renewal of the arms and trunk. Renewal of the arms is brought about by cutting away all or a portion of the old arms. Canes which have originated near their base will serve as the new arms with their outer portion brought more or less obliquely to the upper wire the first year. For trunk renewal a well-grown shoot arising near the ground is tied to the lower wire, and the process of training repeated.

Disadvantages:

1. The pruning operation is comparatively slow.
2. The best canes frequently develop far from the trunk where they cannot be used to the greatest advantage.
3. The fruit near the ground may become quite dirty.

This system is used chiefly in Chautauqua County, New York, and in certain localities in Pennsylvania and Ohio.

Keuka or high-renewal system. This system involves a permanent trunk but instead of 2 permanent arms, as in the Chautauqua system, 2 canes are placed annually to the right and left of the trunk at the lower wire. As they grow the shoots are tied to the upper wires. Usually 3 wires are used, the lowest 18 to 20 inches from the ground and the others at intervals of 20 inches above the lower. The trunk reaches nearly to the lower wire. As might be expected, even more summer tying of shoots is involved than with the other systems, while the fruit which is produced close to the ground tends to become dirty.

It is to be noted that this system involves extraordinarily heavy pruning, a fact which is largely responsible for the lower yields.[25] This system is used chiefly for the Catawba and Delaware varieties in the Finger Lakes region of New York.

The fan system. This system, as indicated, trains the vine in the shape of a fan. The original fan system has almost no trunk and the upper portion of the vine is renewed annually. Canes are tied obliquely from the trunk to the 2 or 3 wires utilized. This system, however, is subject to various modifications; in fact, it is often difficult to distinguish between a modified-fan system and a poorly developed Chautauqua. The modification most commonly used in Ohio (Fig. 56, lower) carries a trunk up to or above the first wire, often in the form of a V. The canes are cut back to 6 to 10 buds and several (usually 3 to 5) are then tied vertically, or in a slightly oblique position to the top wire. The shoots are tied in a more or less upright position to the second wire.

This system has the advantage of allowing some regulation of the number of canes to the vigor of the vine. Although it is not suitable for such vigorous varieties as Concord, it is quite applicable to Catawba and Delaware. In spite of these facts, it remains the prevailing system in northern Ohio Concord vineyards.

In Georgia a modified fan system is used occasionally for Scuppernong grape, and other varieties of *Vitis rotundifolia.*[19, 43]

Systems involving drooping shoots. Single-trunk four-cane Kniffin. This system is the most satisfactory, and the most generally used of all the various methods for training grapes. It involves a permanent trunk which extends to the upper of 2 wires. From the trunk, at the level of each wire, 2 canes, one to the right and the other to the left are selected annually. (Fig. 57.) Two renewal spurs are usually retained at each wire in order to maintain the fruiting wood reasonably close to the trunk. The canes are usually long enough to contain 8 to 10 buds each, with 1 or 2 more left on each of the upper canes than on the lower, since the growth of the vine is greater at the top than on the lower canes. In case of an unusually vigorous vine one or more canes may be left in addition to the customary 4, in order to produce a larger yield, without resulting in weak growth. These canes may be selected near the trunk at the lower wire and tied obliquely to the top wire as in the fan system.

Establishment of the system. In training young plants to this system a cane is brought to the upper wire as soon as the vine is sufficiently vigorous, which is usually by the end of the second growing season in the vineyard. The first canes to be extended horizontally develop as shoots from this cane during the third growing season. Subsequently the canes used develop from the basal buds on the previous year's canes although renewal spurs should be left where possible for the same purpose. Shoots developing from the canes are allowed to droop, no tying being necessary.

The lower wire used in this system is usually 3 to 3½ feet above the ground and the other 2 to 3 feet higher. Taller posts are required and heavier wire than would be necessary for the other systems.

Various modifications such as the Umbrella Kniffin have been used in various parts of the country. In the Umbrella Kniffin, as used in Pennsylvania, the trunk is again carried to the top wire, from the head of which canes are carried obliquely to the lower wire in the form of an umbrella. Two to 4 canes are usually selected. The development of the Y-shaped Kniffin allows bending the canes without so much danger of breakage. These modifications have been shown to result in no higher yields and have no advantages over the single-trunk four-cane Kniffin, a result due in part to the greater amount of wood removed in pruning to these modified forms.

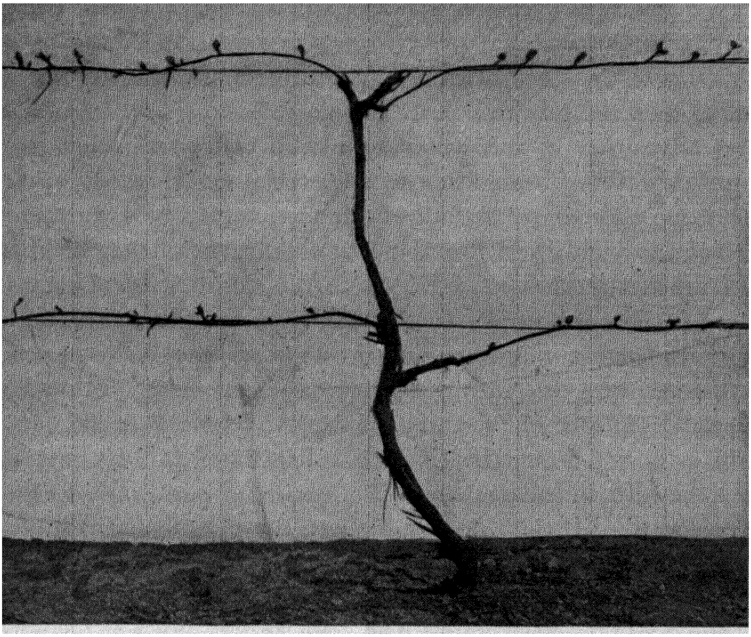


FIG. 57. Grape vine pruned in accordance with the single-trunk-four-cane Kniffin system.

Time of pruning in the North. Grape vines should be pruned while still dormant, but not while the weather is very cold. Experiments indicate that late winter or early spring is most suitable, so long as the vines are still dormant. If pruned late, the vines may "bleed" but, as far as is known, the liquid is largely water, and bleeding will not seriously injure the vine.

Relation of growth to yield. Since the fruit of the grape is produced only on 1-year wood, the purpose of pruning is to insure sufficient new growth for continuously favorable production. In order to induce a vigorous growth of shoots, the amount of wood removed each year must represent a very large proportion of the previous season's growth. Furthermore, pruning is necessarily severe in order to keep the production of new growth close to the trunk, thus taking advantage of the water supply in order to induce greater vigor. A considerable amount of experimental work has been carried out with grape varieties to determine the exact relationship of growth to yield,[16, 47, 48] and particular attention has been given to the amount and type of growth. As a result it has become evident that the amount of growth during the current season depends to a considerable degree upon the vigor of the vine during the previous season. If fruiting at that time was excessive, with consequent depletion of food materials, the growth of the current season is much reduced. On the other hand the current year's growth is also influenced by the amount of pruning carried out just previously. If this was insufficient, the number of fruit clusters is excessive, growth is much reduced, and the fruiting clusters are small and not well filled. On the other hand if too little wood is left, the yield is greatly reduced, the shoots become excessively vigorous and relatively unfruitful. In theory it is preferable to leave just enough buds to allow for the exact number of large sized clusters compatible with a good but not overvigorous growth. The optimum number of buds to leave per vine is influenced by several factors such as variety, age, and vigor of the vine, system of training, and type of cane. In general, experiments indicate that the best number is approximately 40 per vine. In some states, however, it is thought that vigorous vines of Concord and Niagara can support a somewhat larger number.

Index of fruitful type of growth. Particular attention has been given to indices for the selection of the most fruitful canes at the time of the dormant pruning.[16, 47, 48] In Michigan where the work has been most extensive, the Concord and Campbell Early varieties were observed. Cane diameter, length of internode, and length of cane have received particular attention.

Cane diameter. In Michigan, Concord buds were found to be more fruitful on canes ¼ inch in diameter (or slightly more) when measured between the 5th and 6th nodes, than on canes of either much greater or smaller diameter at a comparable position. In general, work in Missouri, Iowa, Illinois, and Maryland indicates that canes of this diameter, or those slightly larger, were the most fruitful. In the Campbell Early variety it was found that the canes should be at least ⅜ inch in diameter. In all instances, in this variety, the larger canes were the most fruitful, but there was found to be little correlation between the length of internode and the productivity of this variety.

Length of internode. Concord, however, showed a definite association between the length of the internode, between the 5th and 6th bud, and fruitfulness. Buds on canes which were ¼ inch in diameter and had an internodal length of 5 to 8 inches between the 5th and 6th buds were the most fruitful. If it comes to a choice between canes of greater or smaller diameter, or between canes of longer or shorter internodal length, those slightly larger in diameter, and those slightly longer between the internodes should be chosen. The least productive canes are small in diameter and have a short distance between buds. Canes which taper very rapidly are never sufficiently productive.

Length of canes. Some attention has been given to the relationship between length of the cane and fruitfulness. In general the data indicate that canes 7 to 9 feet, depending upon local conditions, are the most fruitful although variations of one foot in either direction are not particularly critical.

Location of the fruitful buds on the cane. The buds near the base and the tip of the cane are less fruitful than those in an intermediate position. In Michigan, the buds from the 3rd to the 9th node produced the largest amount of fruit. Usually the first 2 buds are relatively low in yield while the 8th to 10th buds are more productive. The smaller canes show a greater decline in productivity near the tip than canes of intermediate or large diameter. Thus when small canes are chosen they should be pruned to a shorter length than larger ones. Furthermore, small-diameter canes permit the development of only a relatively few shoots. A small diameter cane should be permitted to carry no more than 6 or 7 buds. Occasionally the most vigorous canes produce laterals due to vigorous growth the previous season. These laterals may be used but they should be cut back to spurs of 2 or 3 buds each. It has been determined that these buds are actually more productive than those on the parent cane if the latter measures well over ¼ inch in diameter. Where parent canes are less than ¼ inch the buds on the laterals are less productive than those of the parent cane. Laterals from weak or small canes should not be used.

Training and pruning Muscadine grapes. Muscadine grapes are trained by either of two methods, one called the Horizontal or Overhead and the other the Upright or Vertical system. The latter is more satisfactory than the overhead method for commercial vineyards. These methods are discussed in recent publications.[19, 43]

Pruning Vinifera grapes. The systems of training and pruning as applied to Vinifera grapes are numerous and diverse. This is due in part to the long period of time over which European grapes have been cultivated and the gradual adaptation of some of the Old World methods to new conditions in California. Such systems of pruning do not apply to the Eastern grape varieties which have originated as hybrids of native species or of native species and varieties of *Vitis vinifera.*

Examination of the available data regarding the interrelationship between pruning and growth and fruiting of the Vinifera and Eastern varieties shows definitely that the fundamental principles are much the same.[62] Pruning particularly depresses the ultimate growth and fruiting of the vines. Unpruned vines invariably produce a greater amount of fruit until the time when bearing exhausts the reserves of the plant, whereupon growth is reduced to a minimum. Severe pruning not only greatly reduces the yield but also the growth of the vine to an undesirable degree. There must exist, therefore, a proper balance between growth and fruiting which in Vinifera grapes, is maintained by a moderate pruning supplemented by thinning the flower clusters before bloom and clusters or parts of clusters after the fruit has set.[62]

The Raspberry, Blackberry, and Dewberry

Intelligent pruning of the bramble fruits depends upon a knowledge of their growth and flowering habits. Each year new shoots grow from buds at the base of the old canes or crown, while in addition the red raspberry and blackberry produce shoots, called suckers, that spring from adventitious buds on the roots. These shoots grow vigorously and during the late summer and early fall differentiate flower buds. Early in the second season the buds on these 1-year-old canes (last-year shoots) produce shoots bearing leaves. These leafy shoots have both single flowers and flower clusters. After fruiting the canes gradually become desiccated and die, while the roots grow for many years.

These fruits differ from the tree fruits and the grape in that they are subject to *summer* as well as *dormant* pruning. The principal facts in regard to their pruning will be considered under these two categories. Particular attention is given to this training as carried out under Eastern conditions, although variations which occur in other regions are noted.

Use of supports and trellises for bramble fruits. Usually the black and purple raspberries are grown without supports. However, in certain areas, such as in California, trellises are used for drooping varieties, or to support an exceptionally vigorous growth. In the East, the trellis, if any, is very simple, consisting of two wires strung lightly over nails in "interior" posts. The wires 18 to 24 inches high, may be easily let down in order to facilitate pruning. The canes may or may not be tied to one of the wires.

Various types of trellis are feasible. The wires may be stretched over the ends of X-braces or on cross arms set on stakes or posts 24 to 36 inches high, the posts being set at appropriate intervals in the row.

In California, posts are set at regular intervals and short cross arms 18 to 20 inches in length nailed to the posts 2½ to 3½ feet above the ground. Wires are stretched from post to post along the ends of the cross arms and the plants are pruned as they grow up between two wires. As a rule additional tying is necessary.

The red raspberry is commonly grown in accordance with several systems of planting, namely, hill, hedge row (wide and narrow), and linear.[57] In certain areas, such as the Hudson Valley in New York and in Illinois, the hill system is preferred.[14] Three to 8 canes, 4 to 6 feet tall, are left to each hill in pruning. They may or may not be staked. The hill system has the advantage of allowing cross cultivation, but it tends to result in a lower yield per acre and mosaic may spread more rapidly.[57] Commonly in the East the suckers are allowed to develop and to form a hedge row. A narrow rather than a wide hedge row is preferred in commercial plantings. In the narrow hedge row as found in New York, the rows are 7 to 8 feet apart. The row is restricted by cultivation to a width of 1 foot. Higher yields are obtained by this system and the evils of a hedge row 2 to 3 feet in width (wide type) are avoided. In the linear system, which is preferred on the Pacific Coast only the original plants are allowed to fruit, all suckers being removed.

In many red raspberry areas, supports or trellises are used. When the red raspberry is grown in the hedge row a series of posts with cross pieces may be set up. Wire is strung along each side of the row and attached to the end of the cross pieces. In general, a supporting trellis seems preferable rather than to resort to heavy dormant heading back.

Erect growing blackberries are usually pruned so that they do not need support although in certain areas it is sometimes provided, while *trailing* blackberries are customarily trained on a trellis. Dewberries are usually tied to stakes; although occasionally they may be allowed to grow without supports, being kept in place by cultivation.

The trellis, used for trailing blackberries varies in accordance with the locality. Variations consist in the number and location of vines, location and distance between posts, and other factors. The canes which have not yet fruited are frequently trained on an overhead trellis raised 2 feet above the fruiting canes. In other instances the fruiting canes are trellised above the nonfruiting ones. These canes are held in place by wires attached to horizontal cross pieces 18 to 20 inches long and nailed to posts placed at regular intervals in the row.

Pruning the bramble fruits. The pruning of the various bramble fruits is discussed under the following headings: summer pruning and dormant pruning.

Summer pruning. The bramble fruits differ in respect to summer pruning. The black raspberry, purple raspberry, and the blackberry are "pinched" or "topped" while the red raspberry is almost always left untouched at this particular time. The procedure involves the removal of the tip of the shoots when they have reached a certain height either in May or June. This pinching forces the shoot to branch, thus inducing strong lateral shoots, and a stocky type of growth. Although this method is found to be effective in the case of the fruits above-mentioned, pinching the red raspberry usually results in weak laterals which are easily winter-killed [34] and in sucker growth. However, in Georgia where winter killing is not a hazard, the tips of red raspberry shoots are pinched back at a height of 30 inches.[63]

The height to which plants are pinched back is in general quite uniform, although due to local conditions and other factors, authorities differ slightly in their recommendation. In New York [57] and Ohio,[56] it is recommended that the black raspberry be pinched back to 18 to 24 inches; the purple, 18 to 30 inches; and the blackberry at 24 to 30 inches. In Illinois [14] the distance recommended for the black raspberry is 21 inches, while it is recommended that the purple raspberries and blackberries be topped at 30 to 36 inches. In Michigan the minimum height for the black raspberry is 24 inches and 30 to 36 inches for the purple.[38] In California it is recommended that the tips of young black raspberry plants should be pinched when they are 12 inches high.[11]

It is necessary to go over the field frequently in order to keep the shoots at the desired height. The shoots should be pinched back when they have exceeded the desired length by 2 to 4 inches, thus preventing a waste of nutrients and food materials.

The second operation applicable to these fruits is the removal of the canes after fruiting. Whether they are removed immediately after fruiting, or at the end of the following winter, generally depends upon whether they are intended as support, or to protect the shoots from breakage during the winter. In general, it seems advisable because of disease prevention to remove the canes after harvest, although, in certain instances where the winters and snow are severe, the old canes are left until later.

Dormant pruning. The dormant pruning (other than in the red raspberry) consists largely of thinning out canes and heading back the laterals produced as a result of summer pruning.

Thinning the canes. As previously indicated, the bramble fruits vary in shoot production, particularly in adventitious shoot growth. Because of its many suckers the red raspberry soon becomes a thicket unless the excess is removed either during the summer, as they develop, or at the dormant pruning. The varieties, June and Marlboro, sucker sparingly while Cuthbert and Newburgh produce a large number.[57] In Michigan [60] it is recommended that not more than 7 to 9 canes be left to each hill of red raspberries since beyond that point the yield decreases in proportion to the number of canes per hill. The general recommendation is no more than 10 red raspberry canes to each 4 feet of hedge row. Furthermore, following removal of weak canes the strong canes should be thinned out to a distance between canes of 4 to 8 inches depending upon local considerations.

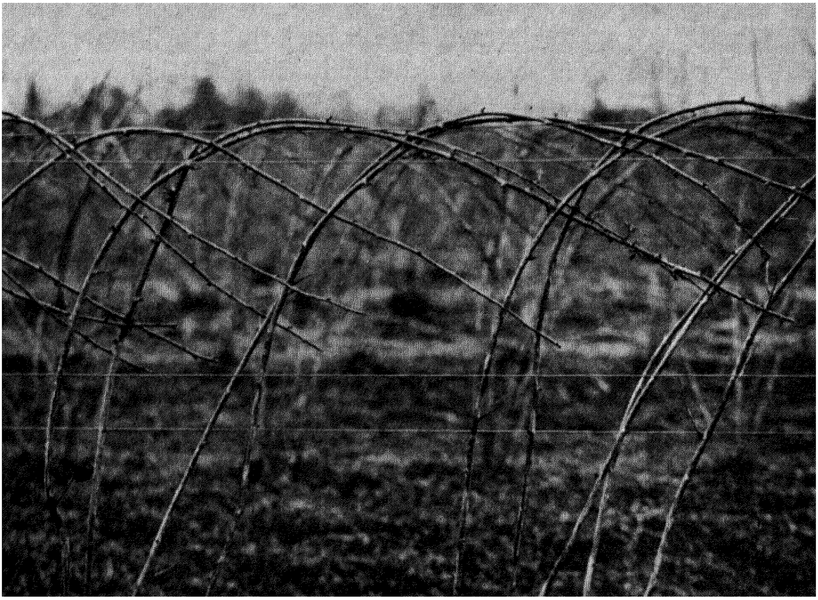
Other studies indicate that the average, vigorous black raspberry plant can support all canes which have achieved a diameter of $\frac{1}{3}$ inch. On the other hand a diameter of $\frac{1}{2}$ inch determines the selection in the case of blackberries and purple raspberries, which require very little cane thinning.[14, 57] In this way all small, weak canes are removed at the dormant pruning and the number of strong canes is determined in accordance with the vigor of the individual plant.

Heading back of canes or laterals. Red raspberry. In this fruit the unbranched canes are usually headed back, the extent depending upon various considerations. The canes are left 4 to 6 feet long depending upon local conditions, such as vigor of the plant and the variety. Experiments indicate that only the slender, relatively weak growth of the top portion should be removed.[10, 34] If much of the plant is suppressed the crop is decidedly reduced, due to the unfruitfulness of many of the buds induced to produce shoots as a result of the heavy heading back.

Studies indicate that high-yielding shoots begin at the base and continue through the fourth and fifth foot sections of the cane. In Michigan, numbering from the base of the cane the first 5 buds were most productive; the 10th to the 15th ranked second. The yield of the lateral shoots developing from the 15th bud to the top of the cane decreases progressively. The largest yields were naturally obtained from the most vigorous canes. On light soils subject to drought, the canes may be cut back more severely than on well-watered soils. In California canes are cut back to 3 to 4 feet according to the nature of the growth and the training system involved.[11]

Laterals developing from these canes should be cut back to 10 or 15 buds—that is, to about 10 inches.[34, 57] It was found in Colorado that the first 5 buds on these laterals were quite unproductive. The yield, which was at its highest between the 10th and 15th buds, fell off rapidly beyond that point.

In the Pacific Northwest the red raspberry is trained to one of two methods, "topping and tying," or "weaving." [26, 37] (Fig. 58.) Topping and tying involves heading the plants to a height of 4 to 5½ feet and tying to one of two wires supported by cross arms attached to posts. The canes are tied in bunches of 2 or 3, while the young shoots are permitted to grow loosely, between the wires. Topping lowers the fruiting area of the canes, while in weaving, the canes are not cut back as severely. Both the single and double weaving methods are employed. When the double system is used the canes are divided into halves so that one-half is woven on each wire. The canes are placed on the outside of the wires and are carried up and over and down on the near side. The canes at the ends of the rows are fastened down with string, but no further tying is required after the weaving is started, since the canes are brought over and down and tucked in behind the canes which are already in place.



(Courtesy C. D. Schwartze, Western Washington Experiment Station, Puyallup, Washington.)

FIG. 58. Method of weaving Cuthbert red raspberry canes at Puyallup, Washington. This method is used by approximately one-half of the present growers in Western Washington.

With the single weave system all the canes are woven on a single wire. The chief objection to this system is the rèsultant crowding. Weaving should be done in early spring when the canes are less brittle.

Black raspberry. Since all the terminals of the black raspberry have supposedly been pinched back during the previous summer, the pruning operation is concerned chiefly with laterals. Any terminals which remain are usually weak and should be cut back just above a large lateral.

The severity of the heading back of laterals depends upon the variety, probable moisture supply, and local conditions generally. It has been found that the buds producing fruit of the largest size and best quality are found near the base of the laterals and on the main stem.[32] When the laterals are cut back short the proportion of fruits developing from shoots of the main cane is increased. Thus in spite of the fact that the laterals are cut back quite severely the yield may not be significantly reduced. A severe pruning of the laterals has also been found to increase the percentage of berries which mature early, thus reducing the length of the picking season. Longer laterals increase the number of berries at the expense of size. In view of these observations it is usually recommended that, on vigorous canes ½ inch in diameter, the laterals should be cut back to 4 to 7 inches the first year, while in mature fields the laterals may be left at from 8 to 12 inches.[38] Data obtained in Ohio during the 1930–35 period showed but little difference in the yield of Cumberland between laterals left at 6 to 8 inches and those left from 8 to 12 inches.[27] (Fig. 59.)

Purple raspberry. The purple raspberry is treated like the black raspberry except that allowance is made for the greater vigor of the hybrid. Varieties also differ in the number of buds specified for a given length of lateral. Furthermore, in certain varieties, such as the Cardinal, basal buds are less productive than those of other varieties. For this reason recommendations on the basis of length of lateral are rather unsatisfactory. In Missouri the recommendation for Cardinal is to leave laterals 18 to 24 inches,[58] while in Ohio [56] a length of 6 to 10 inches is specified for the first year and 10 to 14 inches for succeeding years. Similar recommendations for Columbian are found in other regions.

Blackberry. The pruning recommended for the *erect* blackberry differs somewhat from directions for the trailing sorts. Blackberry varieties differ also in the ratio of buds to a given length of lateral.[58] In certain varieties such as Lawton, Ward, Early Harvest, and Robinson a large number of buds occur at the base of the lateral, while Snyder, Taylor, and Eldorado produce the greater proportion of their buds at the tip. In the varieties Ancient Briton, Wilson, Ohmer, and Mersereau, the buds are scattered more or less uniformly along the lateral. In view of these differences it is recommended that the varieties in which the buds are concentrated at the base of the lateral should be headed back more severely than those in which the buds are located more or less uniformly along the lateral or near the tips. In Missouri [58] it has been recommended that Early Harvest and Robinson be shortened to 10 to 15 inches and Snyder, Eldorado, and Taylor, to 18 to 24 inches. With the varieties prominent in Illinois [14] it is recommended that laterals be left 12 inches long. Eldorado is to be left at 18 inches. Recently in West Virginia [13] Eldorado plants on poor soil fertilized with nitrogen produced the greatest yield on 4-bud laterals of 12-inch length.

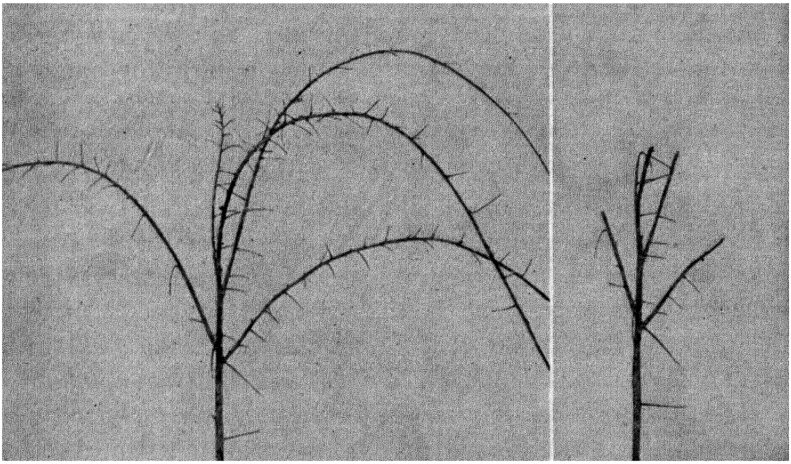


FIG. 59. Mature black raspberry plant before (left) and after (right) heading back of laterals in the dormant pruning.

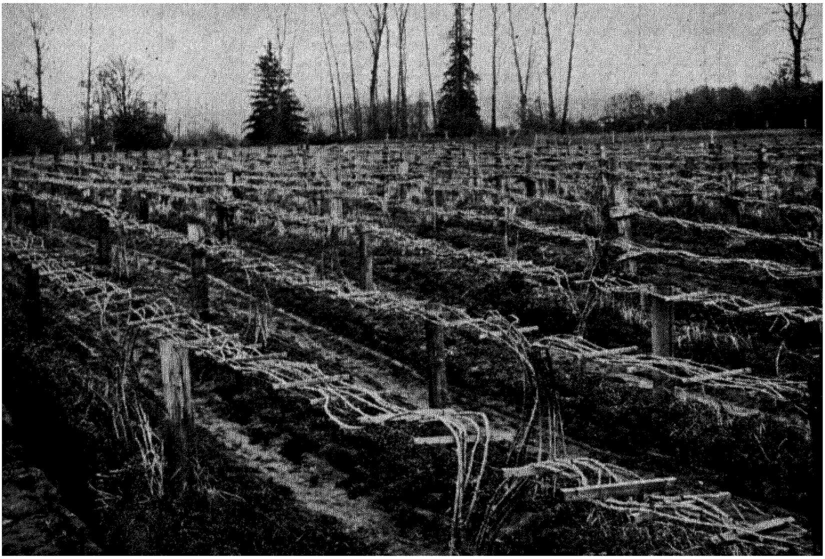
The *trailing* blackberry types are frequently trained in accordance with what is called the *weaving* and the *rope* systems.[11, 26, 37] In the former the canes are woven in and out over two sets of wires on a trellis. This permits greater exposure of the leaves to sunlight but involves more labor than the rope system. In the rope system the canes are taken from the ground where they developed and are tied in several places to either 1 or 2 wires. In Oregon both systems are commonly used, while in Washington the weaving method is preferred and in California the rope is more frequently used. In the weaving system each cane is woven separately on the wires while in the rope all canes are tied together at one time. In California the ropes are often divided into two parts, one part to the lower wire and the other to the upper. Furthermore, at each wire half are taken to the right and half to the left. Although they may be placed on a single wire trellis this is not recommended, due to the dense crowding and shading which results.

Immediately after harvesting the canes which have fruited are cut out and the new ones trained to the trellis. In the loganberry the old canes are cut off close to the ground. In the youngberry in California the growers cut off both young nonfruiting canes and the canes which have fruited, after harvesting, thus depending upon a new growth of canes for the subsequent year's crop.

In Washington the Evergreen blackberry and the loganberry are frequently trained in a manner quite similar to that used for the red raspberry. The trellis used for each consists of 4 wires attached to cross arms which are nailed to posts 16 to 18 feet apart. In the overhead system of training the top wires are about 6 feet and the lower about 4 feet above the ground. Cross slats are placed between the 2 wires on each level. On this trellis the young canes are trained to the top wires, where they rest until they are used to replace the fruiting canes on the lower pair of wires. On the other type of trellis the lower pair of wires are 2 feet and the upper pair 4 feet from the ground. In this instance the young canes are trained on the lower wire until they are utilized to replace the fruiting canes on the upper wires. (Fig. 60.) In both types of trellis the canes are woven over and under the cross slats in a serpentine fashion.

In California [11] trailing varieties like the Himalaya, Brainerd, Mammoth, Cory, loganberry, and youngberry are cut back leaving 8 to 16 feet according to the distance between plants. New canes are allowed to grow along the surface of the ground under the row during the first season. After the first growing season they are trained to 1- or 2-wire trellises, in accordance with the rope or weaving systems. Another method which has proved successful is to weave the canes around 2 wires of a 2-wire trellis in a loose spiral. The new canes are allowed to lie under the row and are brought up and are used to replace the canes which have fruited and been removed. In another 2-wire system, the lower wire is 2 to 3 feet from the ground, the upper one 1½ to 2½ feet above the lower. The young canes are trained to the upper wire and the bearing canes to the lower, somewhat similarly to the method used in Washington where 2 wires support the young canes and 2 the bearing canes. Occasionally in California the Himalaya berry is trained on a 2-wire trellis, the supporting slats resting on the wires and thus necessitating little tying.

The dewberry. Dewberries are either trained on a trellis, tied to a stake, or allowed to grow along the ground, the latter procedure being less customary. The trellis used varies in number of wires, and the length of the stake varies with different localities. The system of training depends primarily upon the climatic conditions, cost of materials, and the personal preference of the growers.



(Courtesy C. D. Schwartze, Western Washington Experiment Station, Puyallup, Washington.)

FIG. 60. Field of Evergreen blackberries in the dormant season. The new canes have been loosened from the lower wires and placed in their permanent position on the upper wires where they remain through the next fruiting season.

Where stakes are preferred, one is used at each hill. The canes are gathered in a bundle and wound around the stakes in a spiral, tying them in 2 or 3 places. In North Carolina, Illinois, and other states in which the growing season is similar, all canes, both young and old, are removed after harvest, depending upon new canes developing thereafter for the subsequent year's crop. The new shoots are allowed to run along the ground until they (now canes) are tied to the stakes the following spring. This procedure has been adopted because of the difficulty in removing old wood after fruiting. Provision must be made for extremely vigorous growth where this procedure is followed, since the removal of so much leaf surface is an exhaustive process.

In Missouri [58] the canes are allowed to trail along the ground, no provision being made for the support of stakes or trellis. In Georgia,[63] dewberries and blackberries with biennial canes are pruned as are raspberries, using the 3-wire trellis.

The Currant and Gooseberry

The currant and the gooseberry naturally form bushes whose shoots diverge from the base of the plant at the surface of the soil. The flowers are differentiated laterally on the current season's shoots and spur growth. The most productive spurs of the red and white currant and gooseberry are located on wood up to 3 years of age; consequently all branches over 3 years of age are removed annually in pruning.[18] Enough 1-year-old twigs are left to replace those removed. No more than 9 main stems or branches properly distributed are recommended, and the pruning is designed to maintain this number. Branches are rarely headed back. When laterals become too numerous in the gooseberry, enough of them may be cut out to form a fairly open head. Branches that tend to droop should generally be removed, or the berries are likely to become dirty.

The weaker growth should be removed from 1-year-old red or white currant bushes, leaving 6 to 8 main branches, depending upon the growth of the bush. At the end of the second year, 4 or 5 2-year-old and 3 or 4 1-year-old branches should be left, while at the end of the third year, about an equal proportion of 1-, 2- and 3-year-old wood should remain after pruning.[18]

The Blueberry

Pruning is considered to be the most important factor governing the size of the fruits in this genus in which large fruits are so essential. In some cases wild blueberry lands are burned over every third year, which, in addition to controlling weeds, is the chief means of pruning. Cultivated blueberry plants should be rather severely pruned during the dormant season, since, in general, the tendency is to prune them too lightly. The practice must be systematically carried out after the bushes are allowed to flower, which is usually after two years' growth in the field. The flower buds are differentiated laterally on shoots, thus making it necessary to provide for considerable shoot growth each year. In order to accomplish this, some heading or cutting back of the main branches is recommended. In New Jersey an annual cutting back of one-third of the bush to leave only 2 inches of wood above the surface of the soil is suggested.[8] Thus the bearing branches are never more than 3 years old. In Massachusetts [6] no attempt is made to remove a definite proportion of the bush, but a few of the older, main branches are cut back or removed. In Michigan [33] in the varieties Rubel and Pioneer, Johnston recommends that one-third of the old branches should be cut back. All agree that the slender, weak growth throughout the bearing plant should be removed annually. Finally it is usually recommended that on those branches which are allowed to remain, twigs bearing flower buds be cut back to 3 to 4 flower buds. In this respect varieties differ in the amount of cutting back required. Certain varieties such as Cabot have many flower buds in proportion to leaf buds on a given length of twig and must be cut back much more than such varieties as Sam and Rubel which have fewer flower buds in proportion to leaf buds.

Varieties also vary in their habit of growth. They comprise two groups, the one tall and upright, including such varieties as Rubel, Adams, and Rancocas, and the other the short bushy type including such varieties as Cabot, Pioneer, and Harding. With the spreading type, an effort should be made to direct the growth upward. The lower-spreading laterals are removed or cut back to upright-growing twigs or small laterals.

For the first 2 years in the field only the weak, slender wood is removed and the flower buds are removed to prevent fruiting.

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10

FRUIT SETTING

The fruit-setting period is a perennial source of anxiety to the grower, since it is accompanied by a greater degree of uncertainty than any other period during the growing season. The climatic factor figures largely in this uncertainty, since late frosts, or an unfavorable blooming season, may seriously reduce crops which, otherwise, have excellent prospects.

Experience shows that certain precautions will reduce the hazard of unfavorable weather. The selection of a proper site and a wise choice of varieties have already been emphasized, but the grower must familiarize himself with all the various factors affecting fruit development in order to minimize the losses and compensate in part for the unfavorable factors.

Pollination, which is one of these compensating factors, has been so constantly emphasized that growers are somewhat inclined to think of the whole problem in terms of this phase. Pollination does deserve a prominent place, and yet research constantly emphasizes the fact that other aspects should receive attention commensurate with their importance in the whole chain of events leading to fruit development.

Processes Leading to Seed Development

It has become evident that fruit setting is influenced by a series of events which take place during a time interval extending from the previous fall up to and including the last period of abscission in July. There can be no adequate understanding of fruit setting, unless one is familiar with these processes within the flower which lead to seed and fruit development. They are given in detail in botanical texts to which the student is referred, and will be briefly outlined here.

The discussion properly begins with the development of the sporogenous cells within the anthers and the ovule, which give rise eventually to the pollen grains and embryo sacs. The consecutive stages involved in seed development are given in order as follows:

1. Processes occurring within the anther and the ovule which finally result in the formation of pollen grains and the embryo sac.
2. Dehiscence of the anthers and transfer of pollen to the stigma (pollination).
3. Germination of the pollen grains and subsequent pollen tube growth.
4. Union of the male and female nuclei (gametes)—double fertilization.
5. Development of the embryo and endosperm and integuments or seed coats.
6. Further growth of the embryo and utilization of the endosperm (in some cases).

1. Processes occurring within the anther and ovule which finally result in the formation of pollen grains and embryo sac. The development of the sporogenous cells, which leads eventually to the formation of the pollen grain, usually precedes the corresponding development on the female side. The development usually begins in a cell of the subepidermal layer which enlarges and divides. These daughter cells by their division eventually give rise to a cell located several layers below the epidermis of the anther. This cell is termed the microspore mother cell or microsporocyte. This stage of development in the apple [101] and plum [26] is usually attained in the fall while a corresponding development within the ovule does not take place until the following spring.

Coincident with the presence of favorable temperature in the spring, rapid development occurs in the anthers. The microspore mother cell undergoes two nuclear divisions (called the meiotic divisions or meiosis) which result in the formation of four cells called microspores which upon germination or equational division become the pollen grains. The process of meiosis involves two divisions which follow one another very closely. In the course of the first the chromosomes in the microspore mother cell are attracted to one another in pairs. When pairing is complete each member of the pair splits longitudinally into two half chromosomes or *chromatids* which are held together by interchanges between the partners. One member of each pair, consisting of the two half chromosomes, progresses at random to one of two poles until an equal number are present at each pole. Following a short resting stage, the second division occurs which involves the separation of the chromatids into four groups (a tetrad) which become the microspores. Thus the number of chromosomes within any one group is one-half of that found in the original microspore mother cell and is known as the *gametic number.* This is the regular form of meiosis usually characteristic of plants possessing fertile pollen grains and egg cell. Irregular distribution of the chromosomes at this stage in the formation of the sex cells leads not only to pollen sterility but also to a comparable sterility on the female side, although in the latter case it is usually much less pronounced than on the male side.

This difference in the distribution of chromosomes in meiosis may be due to several causes, one of which is the difference in the number of chromosomes. Several fruit plants considered in this text include varieties which possess different numbers of chromosomes. In some of these the distribution at meiosis is regular, in others irregular. For example, the plum comprises a number of species and varieties of which the native species *Prunus americana,* the Japanese plum (*Prunus salicina*), Myrobalan plum (*Prunus cerasifera*), and the European plum (*Prunus domestica*) are the most important. All varieties of these particular species except the European plum have 16 chromosomes while the varieties of the European plum possess 48. The number of chromosomes in either the pollen or the egg cells of the varieties with the lowest number (16) is obviously 8 which is the lowest number found in the gametes of any known species or variety of plum. Because of this fact it is called the *basic number.* In the plum the chromosome number of all other species and varieties having more than 16 chromosomes is but a multiple of this basic number. A comparable situation occurs in certain other fruit plants, species and varieties of which are known to have even- as well as odd-numbered multiples of the basic number. For example, in addition to the varieties having the simplest somatic number (2 times the basic number, and therefore called a diploid) forms may occur having 4 times the basic number, called tetraploid; 6 times, called hexaploid; 7 times, called octoploid; and so on. On the other hand the varieties which possess *odd-numbered* multiples of the basic number of chromosomes would be called triploid, 3 times; pentaploid, 5 times; heptaploid, 7 times; and so on. Thus these species and varieties constitute what is called a polyploid series and the condition is known as polyploidy.

In addition, an irregular distribution of chromosomes may occur to a limited extent, even in varieties which possess an even-numbered multiple of the basic number of chromosomes. This tends to be the case in varieties which have originated from crossing individuals of different species. For example, the Duke cherry varieties are similar to the sour cherry in that they are tetraploids (32 chromosomes), but contrary to most sour cherry varieties, they show considerable irregularity in chromosome distribution at meiosis, resulting in much pollen sterility and considerable degeneration of egg cells. The Duke cherries are hybrids of sweet and sour cherry varieties and possess the tetraploid number probably because diploid egg cells of the sweet cherry were fertilized by normal 2x pollen grains of the sour cherry.

Following meiosis on the male side, the four microspores separate and the nucleus of each divides, giving rise to the pollen grain (first stage of the microgametophyte). Pollen grains of the tree fruits are completely formed several days in advance of the opening of the flowers. Within each anther are innumerable pollen grains.

On the female side, the corresponding development occurs several days later than is the case with the male element. Following the formation of the megaspore mother cell (megasporocyte) the meiotic divisions occur, giving rise to a linear tetrad of 4 spores (megaspores) 3 of which normally degenerate. This megaspore which will develop into the embryo sac, enlarges in size and its nucleus divides. The 2 resulting nuclei give rise to 4, and by a third division the 8 nuclei of the embryo sac (megagametophyte) are formed. The 8-nucleate sac is attained in the majority of fruits just previous to the opening of the flower. However, in the triploid apple varieties, the embryo sac usually contains from 1 to 4 nuclei at the opening of the flower (Fig. 61), the number varying seasonally and from flower to flower, possibly as the result of temperature. The final, or 8-nucleate stage, is usually not attained until some time after full bloom.[55]

Recent evidence has shown that environmental factors have a profound effect upon the course of development of the anthers and ovules, during the period previous to bloom. In the strawberry cluster [24] unfavorable sunlight, temperature, and water supply presumably inhibit the development of anthers in many of the first-formed flowers. In the varieties Premier (Howard 17) and Blakemore a rank, vigorous growth also suppresses anther development.[5]

On the other hand pollen abortion decreases in the later opening flowers of all strawberry varieties. Unfavorable nutritive supply resulting from insufficient nitrogen also may result in the suppression of embryo sac development in the strawberry [113] and in the apple.[28, 55]

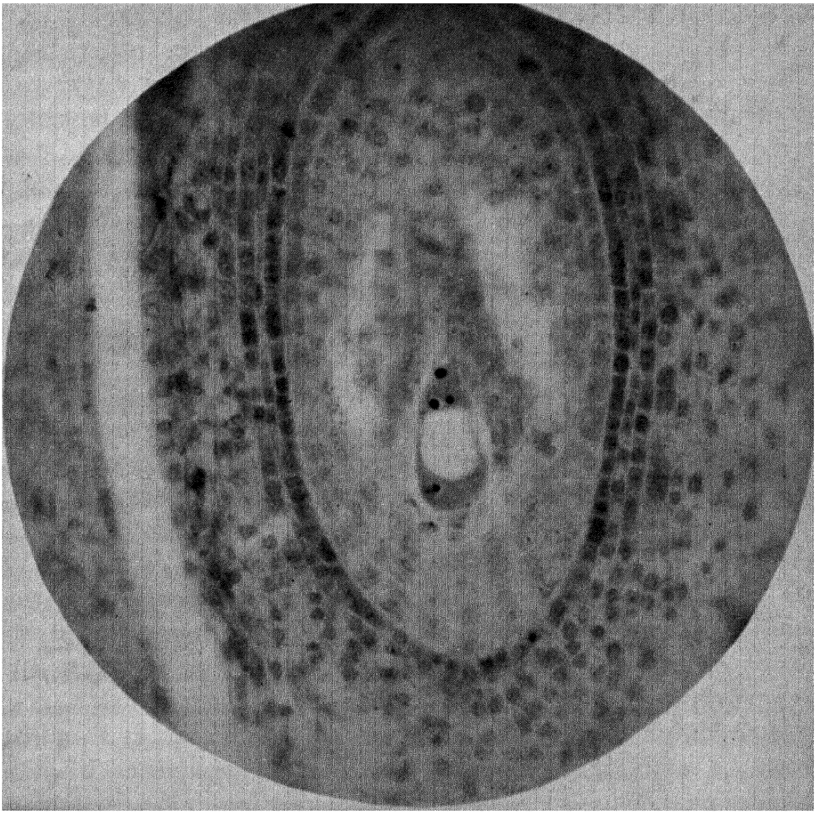

FIG. 61. Longitudinal section through an ovule of a flower of the Baldwin apple variety just as the flower opened. The embryo sac is at the 4-nucleate stage but only 3 nuclei (one with 2 nucleoli) are visible. The tissue in which the embryo sac is embedded is the nucellus. (300X.)

2. *Dehiscence of the anthers and transfer of the pollen to the stigma (pollination).* Dehiscence of the anthers usually occurs within a few hours after the unfolding of the petals, depending upon rainfall,

temperature, and humidity. The effect of these conditions upon the behavior of the anthers will be discussed in connection with the effect of environment upon fruit setting.

In all but a few varieties of the tree fruits, the anthers dehisce even though the pollen may be largely nonviable. Thus, in the Winesap apple, although dehiscence occurs, development does not continue beyond the microspore stage before degeneration sets in.[75]

Transfer of pollen can be effected as soon as the anthers have dehisced, a stage indicated by the presence of a fine yellow powder on the fingers when the anthers are touched. Pollen may be transferred from a flower as long as this powder can be removed, but the period, which is dependent upon weather conditions, is usually limited to a few days only.

3. Germination of the pollen grain and subsequent pollen tube growth. Pollen germination is dependent upon the receptivity of the stigma, a condition assumed to be associated with the secretion of the stigmatic fluid. Experiments indicate that in the tree fruits the stigmas may become receptive whenever they are exposed by the unfolding of the petals, although weather conditions are somewhat influential.[4, 103] Pollination tests show that flowers artificially pollinated 2 to 3 days before the petals normally unfold will set fruit, which indicates that the pollen on the stigma remains capable of germination until receptivity occurs.[4]

The length of the period of receptivity also depends upon the weather. Tests show that, in the apple, pollination must be effected within 2 to 4 days following the opening of a flower, if a high percentage is to set fruit.[4]

After 3 days of bright, sunny weather the stigma usually turns brown, a condition which marks the end of receptivity. In pear varieties receptivity is reported to vary according to the variety; in Conference, 4 days; Beurré Hardy, 3 days; Doyenné du Comice, 2 days; and Pitmaston Duchess, 6 to 7 days.[103] In the plum receptivity is limited to from 3 to 5 days.[27] The period of receptivity is also believed to be extended somewhat if the flower is self- rather than cross-pollinated.

The rate of growth of the pollen tube and whether or not it extends into the embryo sac depends upon the following factors: (a) ecological conditions such as temperature, humidity, and sunshine, (b) relationship of variety of pollen to the variety represented by the style, and (c) the chromosome constitution of the pollen variety.

a. Provided other conditions are favorable, the length of the period from pollination to fertilization depends upon whether or not the prevailing temperature favors pollen tube growth. Within 30 minutes after pollination, tubes may be observed developing from pollen grains. At a favorable temperature many tubes may traverse the style of the apple and plum within 48 hours.[70, 98]

b. The relationship of the pollen variety to the female variety is important in determining the progress of the tube through the style. In those varieties normally producing fruit from self-pollination, growth of the tubes proceeds unhindered through the stylar tissue, and the embryo sac is reached quite readily. On the other hand, when varieties which require *cross*-pollination for fruit development are *self*-pollinated, the growth of the tubes is much retarded, and the majority never attain the embryo sac.[97] Growth immediately following germination may be as rapid as when cross-pollination occurs, but the rate is retarded shortly thereafter, and the tubes eventually burst. Thus, following self-pollination in such plants, the supply of nutrients and growth-promoting substances (phytohormones) are probably not available for continued growth of the tubes. On the other hand, these materials apparently become progressively available for the growth of tubes of compatible varieties.

c. Finally, the chromosome constitution of the pollen variety is an important factor determining the rate of growth of the tubes as well as the length attained. If the variety is diploid, pollen germination will be high (provided the variety is not a certain type of hybrid). On the other hand, if the pollen variety is triploid, the small proportion of tubes which develop will usually elongate only slightly and then burst. Even under the most favorable conditions very few reach the embryo sac and effect fertilization, as is indicated by the poor set of fruit when a triploid apple variety such as Stayman Winesap is used to pollinize Jonathan.

4. Union of the male and female nuclei—double fertilization. Fertilization involves the union of both sperm nuclei from the pollen tube with the egg nucleus and the polar nuclei of the embryo sac. One sperm nucleus unites with the egg nucleus to form the zygote, while the other fuses with the polar nuclei or with a single nucleus, in case the polar nuclei have previously fused, to form the primary endosperm nucleus. This union of the two sperm nuclei with the nuclei in the embryo sac is called double fertilization. That failure to set fruit is occasionally due to the fact that double fertilization did not occur seems probable. Cytological observations at the Ohio Station of the embryo sacs of very immature, abscising apple fruits showed that rather frequently young embryos are present without accompanying endosperm tissue.

As has been indicated, fertilization depends upon the chromosome constitution of the nuclei involved in the process. If the number of chromosomes in either the male or female gametes indicates an unbalanced condition, the amount of fertilization (that is, the number of egg cells fertilized) is considerably reduced. For example, diploid apple varieties pollinated by other diploids (provided one is not a mutation of the other) effect abundant fertilization and a correspondingly high seed content. On the other hand, the opposite is true when a triploid variety is used as a pollinizer for a diploid. When a diploid is used on a triploid, a greater amount of fertilization is effected than with the diploid ♀ x triploid ♂ cross, but the set is less than that obtained from a diploid pollinated by a diploid. The seed content of the fruits is also reduced.[15, 21]

Parthenocarpic fruits. In certain varieties of many species, fruits may develop without fertilization.[32, 60, 79, 80] Such fruits are termed "parthenocarpic." They may infrequently occur in both the apple and pear, but their formation is of little practical importance. Parthenocarpic fruits usually occur under special nutritive conditions, namely, at a time when the parthenocarpic fruits are not forced to compete on the tree with other, normally fertilized fruits. In fact, Kolesnikow concluded that parthenocarpy developed in pears only when reserve carbohydrates were exceedingly high.[60] Parthenocarpic fruits of reputedly excellent quality were obtained in the gooseberry by ringing the stem.[80] Such fruits in the apple and pear are usually smaller than those having seeds. They are frequently of abnormal shape and usually ripen unevenly.

Varieties differ in their ability to develop fruits parthenocarpically. The Baldwin apple and the Flemish Beauty and Bartlett pear varieties are reported to show a "tendency toward parthenocarpy" because fruits frequently occur without well-developed seeds. However, if fertilization has taken place, and minute seeds are formed, the fruits are not, in reality, parthenocarpic. In Vinifera grape varieties, parthenocarpy is of great economic importance. In the currant grape varieties, Black Corinth (including Panariti), Red Corinth, and White Corinth, seedless fruits are produced without fertilization.[80, 106] This is also true of the banana and the navel orange.

Parthenocarpic fruits have been divided into two types not commonly distinguished in a discussion of parthenocarpy, namely, vegetative or *autonomic* and stimulative or *aitionomic.*[106] In the former no pollination occurred and in the latter, fruits have developed as a result of the "stimulus" of pollen tube growth. In connection with parthenocarpy .which occurs naturally, attention is directed to parthenocarpy induced by application of growth-promoting substances, either natural auxins, heteroauxin, or various synthetic preparations.[34, 40] Pollen as well as pollen extracts have been found to stimulate ovary development in some fruits indicating the presence within the pollen of hormones which naturally affect ovary development. The substances, indole-butyric and indoleacetic acids were applied to both the strawberry and the apple. In the strawberry, one flower per cluster developed into a well-formed fruit, while in the apple the results were negative.[34]

5. Development of the embryo and endosperm. The growth rate of the embryo and endosperm depends upon a number of factors, the two most important being the available food supply, including the presence of phytohormones, and the chromosome constitution of the gametes.

Due to what has been termed the "stimulus of fertilization," the pericarp and its associated parts enlarge. (Fig. 62.) The stimulus is now believed to be associated with the production of hormones, the nature of which has not yet been established. These substances are presumably concentrated in the developing seed, and result in the division and enlargement of cells in the pericarp, provided the necessary nutrient materials and water are available. If the supply of these materials becomes deficient, retardation of the growth of the embryo occurs, degeneration sets in, and the fruits abscise. Applications of nitrogen which markedly increase the set of fruit are presumably instrumental in preventing embryo abortion.

Furthermore, rate of growth and extent of development of the embryo and endosperm are believed to be governed by the chromosome constitution of the gametes. Embryonic development is relatively unstable when either of the varieties furnishing the gametes is triploid in composition. The early degeneration of an embryo depends upon the extent of unbalance in the male or female gametes.

Seedlessness occurring despite fertilization. In some varieties of fruit such as certain Vinifera grapes, so-called "seedlessness" occurs even though fertilization has taken place.[106] The embryo and endosperm develop slightly but in the mature berry the seeds are undersized, abnormally shaped, and soft. The name *stenospermocarpy* has been given to this condition which occurs in the seedless grapes Sultanina (Thompson Seedless), Sultanina Rose, and Black Monukka. It is to be distinguished from the *parthenocarpic* seedless fruits occurring in the Corinth grape varieties.[106]

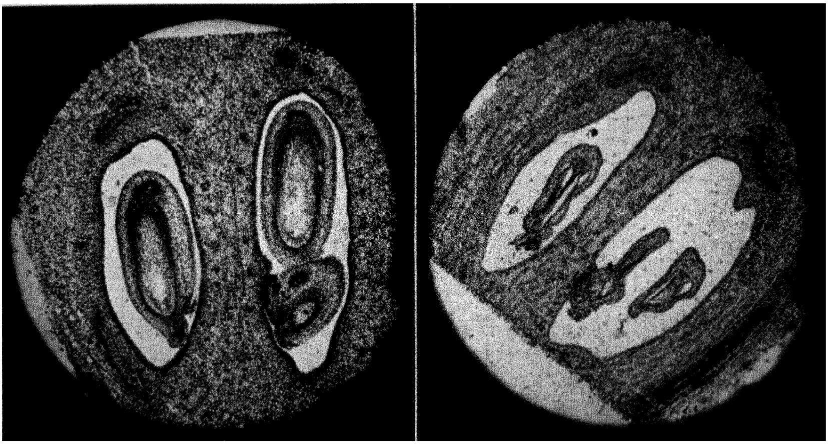

FIG. 62. Longitudinal section through young seeds of a developing fruit (left) and ovules of abscising flower (right). Delicious apple variety. Note shriveling of ovules in consequence of failure of fertilization.

So-called seedless fruits of the apple and pear are frequently obtained in connection with self-pollination experiments,[51, 88] and infrequently following frost injury. Such fruits are not necessarily parthenocarpic even though the seeds are very small and undeveloped.

Seedless fruits of pear varieties have been found to contain less acid, sugar, and insoluble solids than fruits having seeds.[95] The latter were sweeter and more juicy. Seedlessness in pome fruits is likely to be of limited economic importance unless the carpel or seed cavity walls are membraneous and scarcely discernible.

6. *Further growth of the embryo and utilization of the endosperm.* The development of the associated flower parts and the maturation of the fruits considered in this text is positively correlated with con-

siderable embryonic development.[47, 111] In the apple, pear, and strawberry the enlargement of the edible portions is dependent upon the development of at least a moderate number of seeds. In the strawberry, for example, there is a positive correlation between the number of carpels developing into achenes and the resultant size of the berry.[36] With less than 10 per cent of the carpels developing per berry, the average weight per fruit was only 39 per cent of the weight of fruits in which 60 to 70 per cent of the carpels developed into achenes. Flowers of the apple may develop into mature fruits if only 3 or 4 seeds are formed, provided the available food supply is high.[47] (Table 20.) Otherwise a larger number of seeds are required.

TABLE 20. AVERAGE NUMBER OF SEEDS IN DROP FRUITS AND IN THOSE REACHING MATURITY. TAKEN FROM 16 APPLE ORCHARDS.

(From Brittain and Eidt)[15]

Variety	*1928*		*1929*		*1930*		*Av.*	
	Drop	*Picked*	*Drop*	*Picked*	*Drop*	*Picked*	*Drop*	*Picked*
Gravenstein	2.22	3.75	1.98	3.19	2.54	3.60	2.24	3.35
Tompkins King	4.15	5.60	3.55	5.40	3.93	5.99	3.85	5.55
Baldwin	3.80	5.45	3.53	5.54	4.45	5.78	3.96	5.62
Northern Spy	5.61	8.04	5.53	8.58	5.90	8.36	5.67	8.37

It is to be noted in all varieties that the seed content of the drop fruits was appreciably lower than that of the fruits which matured.

A lack of symmetry in the fruit is frequently due to low seed development. This is noted in blocks of apple trees subject largely to self-pollination. Usually when 2 adjacent seed cavities of the apple or pear lack seeds, the fruits are smaller on the side of the seedless carpels.[15] Representative data presented in Table 21 show that apple fruits were malformed when 1.7 to 2.0 carpels were empty.

TABLE 21. THE RELATION OF SEED CONTENT TO ONE-SIDED FRUITS IN BEN DAVIS

(From Brittain and Eidt)[15]

Form of Fruit	*Number of Fruits Examined*	*Average Seed Content*	*Average Number of Empty Carpels*
Normal	94	6.67	0.34
Slightly malformed	30	4.47	1.67
Considerably malformed	79	3.61	2.00

In the pear, asymmetry has been associated with a decrease in the proportion of ovules fertilized. Tissue development in such fruits is relatively more pronounced at the stem end.[95] Müller-Thurgau also pointed out that berry elongation in many Vinifera grape varieties also depends upon fertilization.[79]

Fruits of the cherry and peach usually abscise if embryos are destroyed previous to the beginning of the "final swell" or final enlargment of the fleshy portion of the fruit.[111] However, as a result of such unusual conditions as frosts occurring as late as 2 weeks subsequent to bloom, fruits of the apple and peach [44] have developed without viable seeds. This, of course, occurs infrequently.

Effect of pollen upon the character of the fruit. The effect of the pollen upon the growth and character of fruits as distinct from its effect upon the genetic composition of the embryo and endosperm of the seed, has received considerable attention. For centuries instances have been reported in which size, shape, color, and even flavor of fruits has been affected by the variety of pollen which brought about fertilization in such fruits. The term *meta-xenia* has been given to these effects upon the fleshy tissues surrounding the seeds.[108]

There has been considerable controversy regarding the frequency of meta-xenia in the common, deciduous fruits.[86, 112] Instances have been reported within recent years in which fruit size was significantly affected by different pollens while other investigators have found no meta-xenia in these fruits. Other characters, such as acidity and keeping quality, are also reported to be affected by the variety of pollen.[86] It has become evident that in studying meta-xenia the number of leaves per fruit, and the vigor of spurs and twigs, in addition to other environmental influences, must be taken into account. Furthermore, variations in shape which might be considered an expression of meta-xenia may have been caused by the number of seeds and the nature of pollination as well. Fruits developing from self-pollination in the apple and pear are frequently smaller, and in the pear the tissues surrounding the ovary show less development than occurs in fruits resulting from cross-pollination. Tydeman found that the considerable differences observed in size of fruits resulting from different pollens, became progressively less as the fruits developed, and at maturity amounted to only 10 per cent.[112]

Regardless of the controversy over the frequency of meta-xenia, undoubtedly it is of minor practical importance. Environmental factors, such as temperature, light, water, and available food supply produce much more pronounced effects and mask differences due to pollen. Furthermore, in the several-seeded fruits, pollen from more than one variety may be concerned in fertilization, thus introducing another complicating factor.

FACTORS AFFECTING FRUIT SETTING

The principal factors affecting fruit setting are: 1. nutrients and water; 2. ecological factors, including temperature, rainfall, wind and humidity; 3. pollination and fertilization; 4. pollinizing insects; 5. chromosome constitution of the variety; 6. injury by spray materials; and 7. insect, fungal and bacterial injuries.

Nutrients and Water

A deficiency of any element or nutrient necessary for the development of the essential organs of the flower, or for the development of flowers into fruits, may limit fruit setting.

Nitrogen. Observations and experiment have shown that in America, nitrogen is most frequently the limiting factor. For this reason, applications of this element are now so timed as to insure an adequate supply during the fruit-setting period.

Water. A deficiency of water may also limit fruit setting. However, in humid, nonirrigated regions, the water supply of the soil does not usually fall to the critical point until some time after bloom when the trees have set fruit. It is probable, however, that competition for water may be responsible in part for the abscission of immature fruits despite a relatively high soil water content. In addition fruits of the strawberry and raspberry may be malformed as a response to deficient water during the fruit-setting period.

Pruning. For years pruning has been considered one of the most effective means of increasing fruit set, not merely on trees making a slow growth but also upon those notoriously light in their setting proclivities. In fact, it has been effective when other practices have failed. For example, Paddock and Whipple [92] reported the favorable effect upon the Beurré d'Anjou pear, a notoriously light-setting variety, a result which was verified later.[2, 104] The set of Pitmaston Duchess, a triploid pear variety which usually bears lightly, was also greatly increased by a dehorning type of pruning.[104] In addition, the triploid apple varieties, Stayman Winesap [53] and Rhode Island Greening [46] have responded favorably to moderately heavy pruning, and Delicious, which, in certain cases, may undergo an abscission of over 95 per cent of its flowers, shows a favorable response.[52] Heavy pruning, however, should be employed only as a last resort since it drastically reduces the potential bearing surface.

Ringing. Ringing, which is an artificial device, is found to be variable in its effect.[39, 83, 104] In some cases in the apple in which it did prove to be effective, the results were associated with an increase in the supply of carbohydrates.[39] This means is seldom used because of lack of dependability, but wherever, in particularly stubborn cases, it is to be employed, it must obviously be done not later than full bloom.

With seedless Vinifera grapes, ringing the vines when in bloom increases the number of berries to a cluster. This is of practical importance in Black Corinth which shows a considerable drop of berries when trunks are not girdled. The size of the berries in the Sultanina variety (Thompson Seedless) can be increased when the fruiting canes are girdled at the time the berries are one quarter grown. Normal-seeded Vinifera varieties respond much less effectively to this practice.

The nitrogen-carbohydrate relationship in connection with fruit setting. An unusually heavy abscission of flowers does sometimes occur during the first 2 years of flowering. This is particularly true with the peach and has also been noted in the apple, pear, and sweet cherry. In general, this abscission has been ascribed to an excessively vigorous growth, although the appearance of some such trees would not always indicate it. It is assumed that an unfavorable nitrogen-carbohydrate relationship within the tree is responsible. Since the work of Kraus and Kraybill [61] on fruit setting in the tomato, this explanation has frequently been advanced. Their work shows that rank-growing, vigorously vegetative tomato plants with large thick stems and leaves, will form many flowers which reach full bloom but fail to set fruit. As a result of these data it has been tacitly assumed that a similar condition exists in vigorously vegetative plants of other species and that the aforementioned abscission of flowers on young, vigorous apple, pear, peach, and sweet cherry trees is comparable to that occurring in the tomato.

As indicated in Chapter 3 the abscission of flowers on the vigorously vegetative tomato plants, while usually considered to be the result of an unfavorable nitrogen-carbohydrate balance, is, in reality, associated with carbohydrate (and possibly hormone) deficiency. Such a deficiency, it is true, is the result of an excessively rapid rate of amino acid synthesis, induced by a large amount of available inorganic nitrogen. Insofar as the excessive nitrogen results in a very rapid growth rate, few carbohydrates remain in reserve for the development of the sex organs to a functional condition. The tomato abscission is due to the fact that carbohydrates, though manufactured in sufficient quantity for the growth of the plants, are nevertheless insufficient for the development of functional male sex organs and gametes. This conclusion is supported by the fact that supplementary light causes the flowers of such plants to set fruit.

It is possible that flowers on vigorously vegetative fruit trees also fail to set fruit because of a similar carbohydrate deficiency, but this theory has never been established. In the first place, the flower structure of a tomato as compared to an apple, pear, or sweet cherry is different. Furthermore, the latter require cross-pollination, while the tomato usually depends upon self-pollination for a set of fruit. These factors are pertinent to the problem, since the failure of vigorously vegetative tomato plants to set fruit is due to one of two possible causes. Either the pollen is nonviable, or the length of the pistils and stamens, relative to each other, may be so modified as to decrease or prevent self-pollination. On the other hand, in the fruit tree, such a modification of flower structure would be unimportant since cross-pollination prevails. Thus it seems unjustifiable to apply the explanation pertinent to the tomato to abscission in the fruit tree until more evidence has been obtained from a study of the flowers of the trees involved.

On the other hand, in the strawberry very vigorous plants may show either a slight development of the stamens, or the pollen may be nonviable.[24] A situation comparable to that which is evident in the tomato may also be prevalent here.

It is known that flower clusters shaded with heavy cheesecloth or burlap will not set as well as unshaded clusters.[62] This observation may be of significance in regard to the interior of densely shaded trees where light is definitely a limiting factor. The spurs and branches well within the mature tree and possessing flowers which fail to set fruit exhibit more pronounced symptoms of carbohydrate deficiency than are observed on vigorously vegetative branches of the young, nonsetting trees.

It is also of interest to note that the heavy, early abscission occurring in the tree fruits is not characteristic of all varieties. Some are much more susceptible than others. For example, the first flowers on vigorously vegetative apple trees of Oldenburg, Baldwin, and Wealthy set fruit quite satisfactorily.

Competition between flowers and fruits even in vigorous bearing trees. In spite of adequate nitrogen fertilization and good growth, competition for food materials normally occurs during the fruit-setting period in trees which have been in bearing for some years. The heavy abscission of flowers and partially developed fruits from even a vigorous tree following what has been called a "snowball bloom" is an indication of this keen competition. Furthermore, the increased set of uninjured flowers following severe frost injury before bloom indicates that competition occurs even under presumably favorable environmental conditions.

Ecological Factors

In addition to the fact that unfavorable temperature may kill the essential organs of the flower or seeds of the fruit, temperature, wind, humidity, and rainfall also affect fruit setting because of their influence on: 1. activity of pollinizing insects; 2. dehiscence of the anthers; 3. receptivity of the stigma; 4. pollen germination; and 5. pollen tube growth.

Temperature. In addition to the prevention of bee activity, temperatures below 40° F. either hinder or prevent pollen germination.[38] Tests on hardy tree fruits have shown some germination from 40° F. to 50° F. although the rate of pollen tube growth is greatly retarded.[98] Germination is very satisfactory at 60° F. to 70° F. In fact, data indicate that the whole sequence of events from pollination to fertilization may occur even if the temperature remains somewhat below 70° F. during the entire period.[71] With increase in temperature above 80° F. pollen germination may decrease considerably, but even so germination will be sufficient to effect fertilization.

Abnormal pollen grains, presumably possessing double the usual number of chromosomes, are rather frequently produced, possibly as a result of temperature. Although many of these are viable, they are usually ineffective in fertilization. But unless a very large proportion of the pollen grains are of this nature adequate fruit setting may still occur because of the abundance of viable pollen.

The rate of pollen tube growth increases up to 90° F. to 100° F. But laboratory tests show that the proportion of bursting, and thereby ineffective, tubes also increases as the temperature rises. This is probably unimportant unless the temperature remains above 90° F. for some time.

High temperature may also result in desiccation of the stigmas and possibly the styles, although little is known definitely concerning this phase.

Frost. Varieties of fruits differ considerably in their susceptibility to injury by a temperature below 32° F. In the apple, Delicious is very susceptible, followed by Stayman Winesap, Arkansas, and Winesap. These varieties often come into bloom with a large proportion of the terminal flowers killed by low temperature, but in spite of this, full commercial crops have been obtained. The varieties York Imperial and Rome Beauty usually withstand frosts quite well, a circumstance due in part to their late-blooming characteristic. The amount of injury to the apple pollen at a given low temperature depends upon the variety and the conditions at the time of exposure. But in general considerable pollen is still viable at temperatures which kill the styles and stigmas.[74] In fact it can withstand a temperature several degrees below 32° F. without serious injury.[33, 38, 98]

In some recently reported experiments[33] concerned with the effect of controlled temperatures of 26° F. to 32° F. on apple and blackberry flowers, the first symptom of injury, loosening of the "skin" of the receptacle, was not serious. This was followed, however, by injury to the style. The characteristic browning extended into the placenta and ovules. In the blackberry the first evidence of injury was browning of the style followed by browning of the outer margin of the drupels and extending to the edge of the receptacle. Later the stamens and finally the drupels and receptacle became completely brown.

While temperatures of 30° F. to 32° F. produced no visible injury to apple flowers after 12 hours' exposure, injury was visible at 29° F. Three hours at this temperature, although causing skin loosening, did not injure the essential organs. In general, the same type and amount of injury resulted from short exposure to low temperature as from longer exposure to slightly higher temperatures. The amount of injury increased in accordance with the length of exposure to the temperature.

Wind. Wind in addition to desiccating the stigma and other flower parts may whip flowers so as to destroy their capacity to function. Its most unfavorable effect, however, is the reduction or prevention of bee activity. Trees are sometimes found which are pollinated only on the side away from the wind. This has been noted in orchards bordering lakes or situated where the wind commonly has a full sweep.

Humidity. Excessive humidity may prevent anther dehiscence and thus reduce the possibility of pollen transfer by insects.[27] Flowers pollinated between rainstorms have set well. On the other hand, low humidity, if it results in the drying of the stigma or style, may reduce pollen germination and the rate of tube growth. Little study has been given to this phase of fruit setting.

Rainfall. Continuous rainfall retards bee flight, prevents anther dehiscence, and thus reduces the set of fruit.[27, 38, 45, 98] Trees which have been kept continuously wet by spraying with water for 9 days showed a small fruit set, although much pollen was still viable and many stigmas were still receptive. Short periods of rainfall are apparently only a temporary hindrance to fruit setting, for it has not been demonstrated that rain injures sufficient pollen to limit the supply materially. There is little evidence, moreover, that rains wash any appreciable amount of pollen from the stigmas.[12, 27] However, strawberry plants that are continuously wet during the period of flowering develop fewer and malformed berries.

Pollination and Fertilization

Pollination refers to the transfer of pollen from the anthers to the stigma of a flower. *Self-pollination*, as used in fruit production, refers to the transfer of pollen from the anthers of a flower of one variety to the stigma of a flower of the same variety. *Cross-pollination* refers to the transfer of pollen from a flower of one variety to a flower of a different variety. This definition, it is to be noted, differs from the one used in the botanical texts which defines cross-pollination as the transfer from the anthers of a flower of one plant to the stigma of a flower of another plant. The botanical definition takes no cognizance of the varietal factor which is the keystone of pomology.

The terms *self-unfruitful* and *self-fruitful* have now replaced *self-sterile* and *self-fertile* in indicating the amount of fruit produced in response to self-pollination. *Self-unfruitful*, as commonly used, refers to the production of insufficient fruits following *self-pollination* for "a full commercial crop," while *self-fruitful* indicates the equivalent of at least a *full* commercial crop. The term *partially self-fruitful* serves to describe those varieties and fruits which produce some fruits as a response to self-pollination but less than the equivalent of a full crop. *Self-sterile*, in the strict sense, refers to the inability of a variety to produce fruit with viable seeds following self-pollination, while *self-fertility* involves the production of fruits with viable seeds. These two latter terms refer specifically to seed viability rather than to fruit production and are thus of relatively little importance to the fruit grower.

The terms self-compatible and self-incompatible are occasionally used to denote the capacity of a variety having functional sex organs and gametes to produce fruits following self-pollination. If fruits are not produced, the variety is said to be *self-incompatible* (also self-unfruitful); if fruits are produced, *self-compatible* (also self-fruitful).

The terms, fruitful and unfruitful have a similar use when considered in connection with cross-pollination. If one variety when used as the pollinizer of another is unable to produce sufficient fruits for a full commercial crop the cross is termed *cross-unfruitful;* if fruits are produced, *cross-fruitful.* If the combination is unfruitful because the pollinizing variety has nonviable pollen, the combination is also *cross-sterile.* If both female and male gametes are viable, and yet no fruit is produced, the combination is said to be *cross-incompatible.* If a combination of the two varieties is unfruitful when either one is used as the pollen parent, the combination is said to be *intersterile.*

Examples of the use of these terms may be given as follows:

Delicious apple variety self-pollinated is self-unfruitful and self-incompatible.
Delicious pollinated by Stayman Winesap is a cross-unfruitful combination.
Delicious pollinated by Jonathan is a cross-fruitful combination (also cross-compatible).
Delicious pollinated by Starking (a red strain of Delicious) is cross-unfruitful and cross-incompatible.
Stayman Winesap apple variety self-pollinated is self-unfruitful (also self-sterile).
Stayman Winesap pollinated by Delicious is a fruitful combination.
Stayman Winesap pollinated by Winesap is cross-unfruitful and also intersterile as Winesap is of no value as a pollinizer.
Stayman Winesap pollinated by Blaxtayman (red strain of Stayman Winesap) is a cross-unfruitful and an intersterile combination.

Incompatibility in fruits is explained on the oppositional factor hypothesis advanced by East and Mangelsdorf in 1926.[29] According to this interpretation incompatibility is determined by genes, in a manner similar to morphological characters. Following the terminology commonly used, these genes are designated by the letter S and form a multiple allelomorphic series as S_1, S_2, S_3, and so on. As is the case with other allelomorphs, any two of the above may be carried by a given plant. The essential feature of incompatibility is that pollen cannot function in the style of a plant carrying the same incompatibility factors as the pollen. Thus, for example, a plant of the constitution S_1, S_2 cannot be fertilized by S_1 or S_2 pollen but it may be fertilized by S_3 or S_4 pollen. This interpretation applies only to plants possessing the same chromosome number.

Apple. Pollination tests in the United States, England, Canada, South Africa, Sweden, Germany, and Switzerland have invariably shown that cross-pollination is essential for a full commercial crop.* A few varieties such as Jonathan, Baldwin, Rome Beauty, Gallia Beauty, and Yellow Newtown, will produce a partial crop when self-pollinated, but Baldwin is the only variety of any commercial importance which has been reported to produce a commercial crop under these circumstances. It is now generally conceded that all apple varieties should be interplanted to insure the production of high yields. For this reason there is no necessity for listing the hundred or more varieties tested by various investigators.

Varieties effective for cross-pollination. Considerable work has also been done throughout the fruit-growing regions of the world in order to determine the effectiveness of many varieties as cross-pollinizers. The varieties thus examined fall into two groups, one including those generally effective, and the other comprising those of little or no value. (Fig. 63.)

The varieties having infertile pollen, which are consequently ineffective in cross-pollination, are as follows:

Arkansas (Mammoth Black Twig)	T
Baldwin	T
Belle de Boskoop	T
Blenheim	T
Bramley's Seedling	T
Canada Reinette	T
Crimson Bramley	T
Fallawater	T
Fall Pippin	T
Gravenstein, Red Gravenstein and Bank's	T
Nero	D?
Ohio Nonpareil	T?
Paragon	T
Rhode Island Greening (Fig. 63)	T
Ribston Pippin	T
Roxbury Russet	T
Stark	T
Stayman Winesap, Stamared, Blaxtayman, and Scarlet Stamared	T
Summer Rambo	T

---

* The list of workers on apple pollination is very extensive. It includes the following: 4, 5, 14, 51, 53, 54, 63, 64, 65, 66, 67, 71, 74, 81, 89, 115, 117, 118.

Hibernal	T	Tompkins King	T
Mann	T	Turley	T?
Miami (red strain of Stark)	T?	Virginia Crab	T
Minkler	D?	Winesap	D

The varieties which are effective in cross-pollination are without exception diploid, having 34 chromosomes. On the other hand, those with infertile pollen marked "T" are known to be triploid (51 chromosomes).[77, 85, 96] Winesap is a diploid despite the fact that it has nonviable pollen. The chromosome number of such varieties as Nero, Minkler, and Ohio Nonpareil is unknown. It is unnecessary to test the effectiveness of a triploid variety as a pollinizer since they have invariably proved to be ineffective.

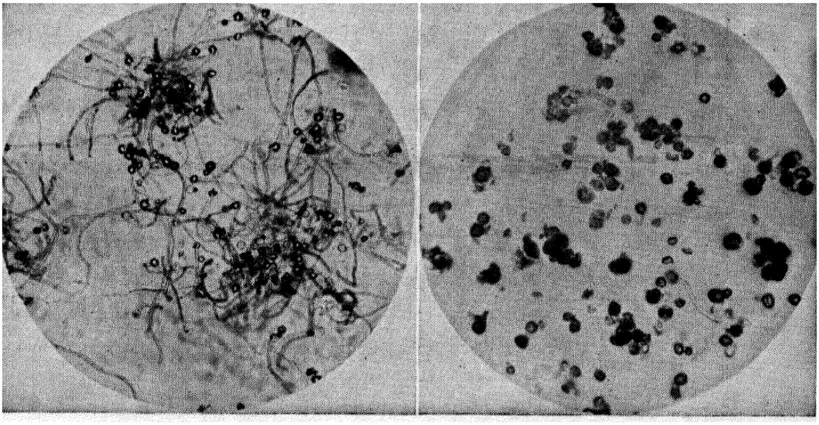

FIG. 63. Typical pollen germination in the Red Spy (left apple) variety and Rhode Island Greening (right). Note large, medium-sized, and small grains in the Rhode Island Greening. (Magnification: Red Spy 50X, Rhode Island Greening 100X.)

Combinations unfruitful because of close relationship. Cross-pollination tests have shown that certain varietal combinations in which the pollen and egg cells of both parents are functional are nevertheless unfruitful. This cross-incompatibility is undoubtedly due to the close relationship of the varieties involved, since the unfruitful combinations are, in the majority of instances, comprised of a variety and its bud mutations or "bud sports." [64, 69, 90] Usually the seedlings of standard varieties are cross-fruitful with the parent varieties. However, instances such as Rome Beauty and Gallia Beauty are recorded, in which a parent and certain of its seedlings are only partially cross-fruitful.[54] Furthermore, the combination of

Cortland pollinated by Early McIntosh is not sufficiently fruitful.[117] Both are seedlings of McIntosh. In all other known instances the various named seedlings of McIntosh are cross-fruitful.[64, 69]

Several examples of such cross-incompatibility are as follows:

Delicious and all its color strains such as Starking, Richared, and Shotwell Delicious
Duchess, Daniel's Red Duchess, and Van Buren Red Duchess
Cox's Orange Pippin and Laxton's Superb
Jonathan, Jonared, and Blackjon
McIntosh and Blackmack, as well as other strains of McIntosh
Northern Spy and Red Spy
Ribston Pippin and Cox Pomona

Grimes Golden is of no value as a pollinizer for either Arkansas (Mammoth Black Twig) or Paragon.[5] This is an interesting fact since Grimes Golden has viable pollen and is presumed to be unrelated to Arkansas.

Combinations not sufficiently fruitful because of disparity in time of blooming. Certain combinations of apple varieties are not fruitful because their blooming seasons usually do not overlap sufficiently. The time of bloom varies considerably in different fruit-growing regions, and in different seasons, but, in general, the relative order of blooming is similar in any one locality. For example, when the temperature is high, the blooming period of all varieties is much shortened and all but the very early or late will overlap sufficiently. On the other hand, if the season is cool the blooming period of the early and late varieties are much more widely separated, and they cannot then be used even as pollinizers for some of the midseason blooming sorts. The early blooming varieties include Red Astrachan, Early Harvest, Gravenstein, Fameuse, McIntosh, Melba, Milton, Oldenburg, Ohio Nonpareil, and Wagener, while the varieties Gallia Beauty, Northern Spy, Macoun, Northwestern Greening, Rome Beauty, and York Imperial are late blooming. Ralls and Ingram are very late blooming.

Bearing age in relation to cross-pollination. Certain two-variety combinations would be unfruitful due to their disparity in time of forming their first flowers. The varieties Cortland, Jonathan, and Golden Delicious, for example, come into bearing early (5 to 7 years) while Northern Spy and Yellow Newtown do not produce flowers until several years later. Other varieties are intermediate in this respect. In choosing pollinizers, intermediate varieties may be selected for the early and late, while obviously the late bearing must depend only upon those within its own group. Any plan which disregards these requirements necessitates the introduction of bloom or hand cross-pollination for several years.

Alternate bearing in relation to cross-pollination. Two-variety combinations consisting of an annual and a decidedly alternate bearing variety are to be avoided. As a rule, however, such combinations are not commercially desirable anyway. The use of a third variety to supplement the pollination of the annual variety will provide for the situation.

Pear. All varieties of the European pear (*Pyrus communis*) and those of hybrid origin such as Keiffer (*P. communis x P. serotina*) have been found to be self-unfruitful.[23, 74, 109, 114, 118] The percentage of flowers setting fruit when self-pollinated is small. Bartlett in some areas in California is reported to be self-fruitful. Usually, however, the set does not exceed 1 to 3 per cent. Since similar results have been obtained in all pear growing regions of the world it is unnecessary to list the varieties which have been tested. Beurré Hardy and Flemish Beauty when self-pollinated have been reported to be sufficiently self-fruitful for commercial crops, but even these varieties should be interplanted for the highest yields.

Effectiveness of varieties as cross-pollinizers. As in the apple, pear varieties fall into two groups: those effective in cross-pollination, all of which are diploid in chromosome number, and those, generally triploid (51 chromosomes as indicated by "T"), which possess nonviable pollen and are consequently ineffective in cross-pollination.[77, 78]

It is true that no commercially important variety in the United States has completely infertile pollen although a considerable proportion of those grown in Europe cannot be used as pollinizers for this reason.[59, 77, 78] The varieties with infertile pollen are:

Alexander Lucas	T	Marguerité Marillat	D
Beurré d'Amanlis	T	Pitmaston Duchess	T
Beurré Diel	T	Pound	T
Catillac	T	Vicar of Winkfield	T
Doyenne Boussock	T		

Combinations unfruitful because of close relationship. Several varietal combinations have been found by various investigators to be cross-incompatible, probably because of close relationship.[74] It is to be noted that in most, if not all instances, the varieties are related to Bartlett. (The female parent is given first.)

Seckel x Bartlett and the reciprocal
Bartlett x Louise Bonne de Jersey and the reciprocal
Seckel x Louise Bonne de Jersey and the reciprocal
Belle Lucrative x Seckel and the reciprocal
Belle Lucrative x Louise Bonne de Jersey and the reciprocal

Blooming season in relation to cross-pollination. Several pear varieties, Howell, Kieffer, Le Conte, Duchess d'Angoulème, and Beurré d'Anjou are early blooming and should not be used as the only pollinating varieties for such midseason blooming sorts as Bartlett, Beurré Bosc, and Gorham. Winter Nelis and Wilder are late blooming and should not be used as the only pollinizers for the midseason varieties.

Age of flowering in relation to cross-pollination. Most varieties bear their first flowers at an age which usually corresponds sufficiently to permit nearly any varietal combination which would be agreeable otherwise. At Wooster, Ohio, however, Beurré Bosc produces its first flowers a few years after Bartlett, thus making the introduction of bouquets imperative. Seckel and Cayuga are also relatively late in producing their first flowers.

Susceptibility of varieties to blight in relation to cross-pollination. Experience shows that where a minimum number of trees are required as pollinizers for a Bartlett planting, it would be well to use at least some trees of a blight-resistant variety, such as Old Home.[57] It may prove necessary to use such a variety of little commercial value for its fruit or one which is not highly productive such as Beurré d'Anjou in order to insure adequate pollination at all times. Otherwise blight may destroy the pollinizers making it necessary to introduce bloom for a number of years. The varieties Beurré Bosc, Clapp Favorite, Flemish Beauty, and Gorham are relatively blight susceptible.

Relation of insect visitors to cross-pollination. Observations in several countries indicate that honey bees prefer the flowers of other fruits to those of pears.[49] Since the pear is not highly productive as compared with the apple, every precaution to insure thorough cross-pollination is imperative. This involves an abundance of bees as well as a system of interplanting which makes available a large source of effective pollen.

Quince. All quince varieties tested in the United States and South Africa have been found to be self-fruitful.[115] These include Orange, Rea, Champion, and Meach.

Peach. The greater proportion of tested varieties are self-fruitful and may be planted in solid blocks of one variety.[10, 18, 37, 58] The self-unfruitful varieties, having nonviable pollen are:

Candoka
Chili
Chinese Cling
Hal-berta
Hope Farm
J. H. Hale
Japan Cling (Japan Golden Giant Cling)
Mikado
Pacemaker
Sargents
Tuscan Cling
Vimy

Provision must be made for thorough cross-pollination of these varieties. In Michigan, Banner, Elberta, Kalamazoo, and South Haven have been found to be very effective in the cross-pollination of J. H. Hale.[37]

Nectarine. All nectarine varieties tested have been found to be self-fruitful. This includes Early Newington, Humboldt, Lord Napier, Sure Crop, and Hunter.

Apricot. Tests made in Germany, Sweden, Italy, South Africa, and California all indicate that apricot varieties are self-fruitful. Pollen of all those examined was viable.

Cherry. All *sweet cherry* varieties tested in the United States, England, Germany, Sweden, and elsewhere have been found to be self-unfruitful. [17, 19, 30, 35, 41, 74, 99, 102, 110, 118] Practically no fruits whatsoever were obtained from self-pollination. Crane and Brown recently reported only 0.6 per cent set from 49,160 flowers self-pollinated in carefully conducted tests at the John Innes Horticultural Institution in England, while from 130,356 cross-compatible pollinations, the proportion of flowers maturing into fruits was 22.6 per cent.[19]

All sweet cherries of any commercial importance have satisfactory pollen germinability.

Not all varietal combinations are fruitful, since there is considerable cross-incompatability between varieties. More than a dozen groups are now known which contain varieties reciprocally incompatible, and the number is being augmented with further research. The varieties within any one group are all closely related, being either seedlings or bud mutations of some parent variety.[19, 35, 41] Such groups are as follows:

1. Napoleon, Bing, Lambert, Emperor Francis, and Ohio Beauty
2. Early Purple and Rockport

3. Advance and Rockport
4. Windsor and Abundance
5. Elton, Wood, and Stark's Gold
6. Black Tartarian, Knight's Early Black, Early Rivers, Bedford Prolific, and Black Eagle
7. Centennial and Napoleon

Group No. 1 contains several varieties commercially prominent in this country. As has been previously indicated incompatibility within this and the other groups is believed to be governed by a series of multiple allelomorphic genes. The varieties within a group contain the same genes in the style as in the pollen, a fact which results in failure of the pollen tubes to reach the ovary and effect fertilization.

Various strains have been found in Napoleon, Bing, Lambert, Black Republican, and Black Tartarian which do not respond equally to pollination tests. In all likelihood this is due to the fact that seedlings of these varieties which now exist are probably so similar in appearance to the original varieties as to make it difficult to distinguish them from their parents. It has thus become necessary in using Black Tartarian, for instance, as a pollinizer, to select trees of strains known to be capable of fertilizing the chosen variety.

Apart from the exceptions aforementioned all varieties are effective in cross-pollination. In addition some Mazzard seedlings are effective on Napoleon, Bing, and Lambert although others are not. Sweet cherries must be planted for cross-pollination of sweet cherries since sour varieties do not overlap the others in bloom, and the Duke varieties give only a partial set when used to pollinate the sweet varieties.[102] A 15 per cent set has been obtained by the use of Duke pollinizers, a set which is equivalent to about half a commercial crop.

Blooming season in relation to cross-pollination. In California the early-blooming sweet varieties are Black Tartarian, Black Republican, Advance, and Early Purple. Rockport, Napoleon, Bing, and Lambert are late blooming and for this reason, Deacon has been planted in Washington and British Columbia as their pollinizer.[41] Black Republican usually overlaps sufficiently to pollinize most of the late-blooming varieties. In the East it would appear that the blooming periods of all the commonly grown sweet varieties overlap sufficiently to permit their utilization as pollinizers for one another, at least in normal seasons.

Sour cherry. The available data indicate that the varieties Early Richmond, Montmorency, Dyehouse, as well as those of the Morello group are self-fruitful, provided sufficient pollinizing insects are available.[30, 74, 99, 102] On the other hand, Chase, Homer, and Ostheim have been found to produce only a small set when selfed,[30] and must be interplanted with other sour cherry varieties. All sour cherries (with the possible exception of Wragg and Ostheim), produce sufficient viable pollen in abundance.

The blooming seasons of all varieties do not entirely overlap. English Morello and Homer bloom very late and should not be planted as the only pollinizing varieties for the earlier-blooming Ostheim. Montmorency is recommended as the pollinating variety for the recently introduced variety, Chase.

Duke cherry. All Duke varieties have been found to produce full commercial yields only when cross-pollinated.

As a matter of fact, the Duke varieties are not highly productive even with the best cross-pollination, a fact probably due to the unbalanced chromosome constitution of much of their pollen and egg cells. Royal Duke and May Duke are usually the most productive, with Reine Hortense following and Olivet and Abesse producing still lighter yields.

The late-blooming sweet cherry varieties are effective in cross-pollinating the earlier-blooming Duke varieties. Napoleon, Windsor, and Wood have shown 25 to 35 per cent set in hand pollination tests on May Duke. On the other hand, the early to midseason-blooming sour cherries such as Montmorency and Early Richmond, are sufficiently effective pollinizers for the later-blooming Dukes.

Plum. European plum. The European plum, *Prunus domestica,* in contrast to the fruits already considered, exhibits a wide range of differences in the response of its varieties to self-pollination. One group is self-unfruitful; in the other some fruits but insufficient for a full crop are produced.[20, 31, 48, 74, 118] Recently Crane and Brown at the John Innes Horticultural Institution in England reported 29.8 per cent set of 21,986 self-pollinated flowers maturing into fruits in the self-fruitful varieties, and 1.5 per cent from 61,688 self-pollinated flowers in 22 varieties in the self-unfruitful group. On the other hand, the percentage of flowers maturing fruit from 51,950 compatible cross-pollinations was 30.32, a value which, it is interesting to note, is almost identical with that obtained from selfing the self-fruitful varieties.[20]

GROUP 1. *Self-fruitful varieties*

Agen
Bavay
California Blue
Coates 1418
Czar
Drap D'Or
Early Mirabelle
French Damson
German Prune
Giant
Goliath
King of the Damsons
Monarch
Ontario
Ouillins
Pershore
Purple Pershore
Sannois
Shropshire Damson
Stanley
Sugar
Victoria
Yellow Egg

GROUP 2. *Self-unfruitful varieties*

Altham
Allgrove's Superb
Anita
Arch Duke
Belgian Purple
Blue Rock
Bradshaw
Burton
Cambridge Gage
Clyman
Coe's Violet
Conquest
Crimson Drop
De Montfort
Diamond
Esperen
Frogmore Damson
Golden Drop
Grand Duke
Hall
Hand
Italian Prune
Imperial
Imperial Épineuse
Imperial Gage
Jefferson
Late Orange
Late Orleans
Miller Superb
McLaughlin
Pond
President
Quackenboss
Reine Claude
Rivers' Early
Rivers' Early Prolific
Sergeant
Silver
Standard
Sultan
Tragedy
Transparent
Washington

Several varieties such as Italian Prune, Agen, Reine Claude, and German Prune appear to be of different strains in different fruit-growing regions. For example, Agen has been listed as partially self-fruitful, at best, in New York, California, and Italy, but as self-unfruitful by Crane in England. Italian Prune is described as self-unfruitful in California, Germany, Bulgaria, and Sweden, but as self-fruitful in New York and the Pacific Northwest. In fact, Einset has recently concluded that a number of the varieties listed in Group 1 should be interplanted with pollinizing varieties to insure consistently full commercial crops.[31]

All of the above varieties, with the exception of Esperen, have been found to produce a high percentage of viable pollen. Except for cross-incompatibility they should be effective in cross-pollinating one another, provided the blooming seasons overlap sufficiently.

The varieties of the subspecies *Insititia* are fully compatible with the other varieties of *Prunus domestica.* Crosses between this species, however, and *Prunus spinosa* (blackthorn or European sloe) as the male parent fail to produce fruit. When varieties of *Prunus domestica* are crossed with the Myrobalan plum (*P. cerasifera*) fruits are occasionally produced but the seeds are imperfect.

Combinations unfruitful because of close relationship. At present four or more groups of cross-incompatible varieties are recognized in the European plum.[20] These groups are comprised of rather closely related varieties. Furthermore, in several instances the incompatibility is not reciprocal as was the case in all instances of cross-incompatibility in the sweet cherry. One of the incompatible groups includes Golden Drop and Jefferson, a seedling of Golden Drop. This group also includes Coe's Violet, a bud mutation of Golden Drop, and Allgrove's Superb, a bud mutation of Jefferson. Another group includes Cambridge Gage, Late Orange, and President. As in the apple and sweet cherry the members of any one group are compatible with any members of another group.

Cross-pollination in relation to time of blooming. In the East the blooming season of the European plums is usually considered to overlap sufficiently to provide adequate cross-pollination. However, in some localities, as at Wooster, Ohio, Italian Prune and Imperial Épineuse frequently bloom too late for adequate pollination by the early-blooming Reine Claude, Lombard, or Grand Duke.

In California the European varieties other than Tragedy and Clyman fall into two rather distinct groups with relation to season of blooming. The midseason group includes Agen, Grand Duke, Diamond, Quackenboss, Jefferson, Standard, Sugar, Imperial, and President. California Blue, Pond, Giant, Italian Prune, Yellow Egg, and Washington bloom later. It is reported that in normal seasons those varieties which bloom later than President are not effectively pollinated by varieties of the early group.[48] Tragedy blooms usually along with several of the late-blooming Japanese varieties, and extends into the blooming periods of Grand Duke and Diamond.

Japanese plum. Pollination tests have shown that the greater proportion of varieties included in the Japanese group (*Prunus salicina*) are self-unfruitful.[31, 48, 118] This includes:

Abundance
America
Apex
Apple
Burbank
Combination

Duarte
Eldorado
Formosa
Gaviota
Kelsey
Prize
Red June
Satsuma
Upright
Wickson

The varieties Beauty, Climax, Methley, and Santa Rosa produce more fruits from self-pollination than the other Japanese plums, but it is recommended that even these be interplanted with other effectively pollinizing Japanese varieties.[26, 48]

In addition, this group is subject to a considerable amount of pollen sterility. The pollen of Apex, Apple, Combination, Eldorado, Formosa, Gaviota, and Kelsey is so low in viability that they are not recommended as pollinizers of any variety.[26, 31, 48] Shiro (generally considered as the Japanese type) has low pollen germinability but may possibly prove effective in cross-pollination. Abundance, Burbank, Duarte, Elephant Heart, Methley, Monitor, Santa Rosa, and Wickson are more dependable as pollinizers although they, too, show considerable sterility.

European and native plum varieties as cross-pollinizers. Varieties of the European plum (*Prunus domestica*) are not consistently effective in pollinizing the Japanese varieties. Recently Einset reported Clyman, Ouillins, Reine Claude, Victoria, and Yellow Egg as giving fair to good sets on the Japanese varieties.[31] This incompatibility between species is probably in part an expression of the difference in chromosome number. Tragedy has been found to be fairly effective for Japanese sorts but the reciprocal relationship is not fruitful. Those of the native American species which possess viable pollen have been found to be the most effective pollinizers of the Japanese varieties.

Native American species and hybrids. The following varieties are self-unfruitful.[26, 116]

Prunus americana: De Sota, Hawkeye, Rollingstone, and Wyant
  Var. *Mollis*, Wolfe
Prunus hortulana: Wayland
  Var. *mineri*, Miner, Surprise
Prunus munsoniana: Wild Goose, Newman
Prunus nigra: Cheney

A number of varieties which originated as hybrids of these species and the Japanese plum (*Prunus salicina*) are not only self-unfruitful but also possess nonviable pollen.[8] Among these are Red Wing, Monitor, Underwood, Elliott, La Crescent, Tonka, Radisson, and Fiebing, all of which are thus of no value as pollinizing varieties. The varieties of native species, Assiniboin, Cheney, DeSota, Newman, Miner, Surprise, Rollingstone, Wyant, and Wolfe also possess considerable nonviable pollen but are effective, nevertheless, in pollinating a number of varieties.[1, 26] Surprise is reported to be the best single pollinizing variety for all the hybrids grown in the Mississippi Valley.

Flowers of the various native species and the Japanese varieties and hybrids show a considerable amount of pistil abortion.[26] Due, however, to their heavy flower production, sufficient fruits are usually produced as long as the varieties are effectively cross-pollinated.

The varieties Oka, Sapa, Zumbra, and Compass, hybrids of the sand cherry (*Prunus besseyi*) produced by Hansen, are also self-unfruitful. In spite of much abortive pollen, Compass is considered an effective pollinizing variety.

Prerequisites of a suitable pollinizing variety for tree fruits. The prerequisites of a suitable pollinizing variety for tree fruits are:

1. Pollen of at least moderate germinability.
2. Compatibility with the variety pollinated.
3. A period of bloom which sufficiently overlaps that of the variety to be pollinized.
4. An age of coming into bearing which corresponds with that of the variety to be pollinated.
5. Regular, annual flower production.
6. Adaptability to the particular fruit region.
7. Commercial desirability.

Suggested planting plans for tree fruits. Apple and pear. Recommendations concerning the best planting plans for the apple and pear are somewhat empirical, yet they are based on observations which cover a wide area. Reports show that in unfavorable blooming seasons, a pollinizing variety located at the outer edge of a solid planting will result in decreased yields on trees at a distance of only 3 rows from the pollinizer. In extremely unfavorable weather, the yield has dropped greatly even on the second row, or on the side of the trees away from the pollinizer. In view of these observations, it would seem advisable that no tree be planted more than 2 permanent rows (apple, 80 to 100 feet; pear, 40 to 60 feet) from the pollinizing variety. This allows pollination of blocks of 4 rows if a pollinizing variety is placed on each flank. Such a planting is shown in Fig. 64, upper. Exceptions may be made in case of such apple varieties as Baldwin, Rome Beauty, and possibly Jonathan,

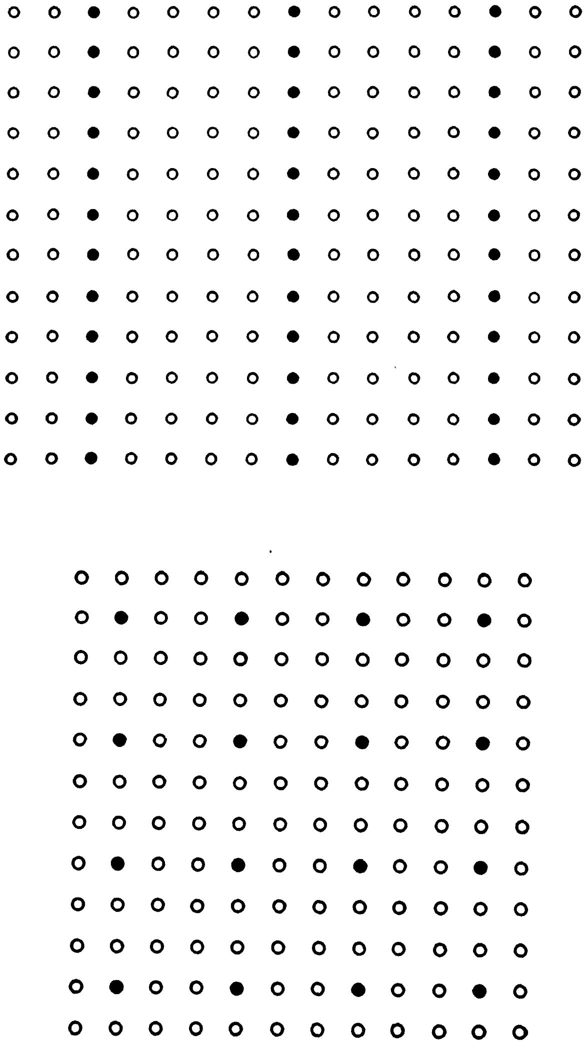

FIG. 64. Suggested planting plans for tree fruits. Upper, plan in which no tree is more than two rows from its pollinizer. Lower, plan in which every third tree in every third row is the pollinizer for the main variety.

which under favorable conditions will produce at least half of a full commercial crop if thoroughly self-pollinated with insects. In this case 8 rows might be planted together with a pollinizing variety on each flank.

A planting plan which allows for a pollinizing variety at every third permanent tree in every third permanent row seems quite satisfactory. It is to be noted that this places a pollinizing tree adjacent in one direction to every permanent tree to be pollinized. Figure 64, lower, also exemplifies this arrangement.

In the pear where particularly effective cross-pollination is essential, and more than the minimum number of a pollinizing variety seems desirable because of its commercial importance, a planting plan such as shown in Fig. 65 may be preferable. This allots about 28 per cent of the planting to the pollinizing variety as opposed to 11 per cent in the case of Fig. 64, lower.

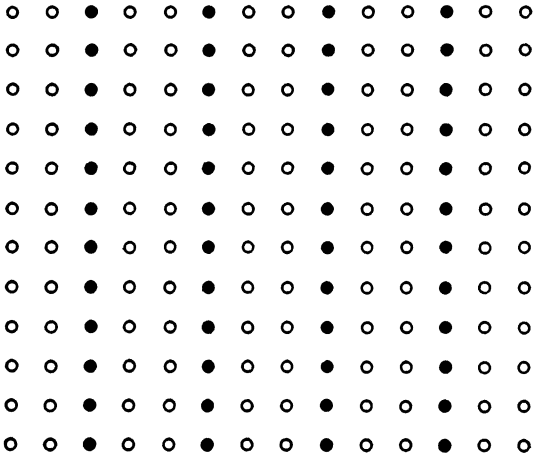

FIG. 65. Suggested planting plan for varieties which require thorough cross-pollination. If the main variety has nonviable pollen, the pollinizing row must consist of two varieties with viable pollen.

Peach. It has been recommended that no more than 4 rows of a self-unfruitful variety be planted together, with a pollinizing row on each flank. (Fig. 64, upper.) In the case of J. H. Hale and other varieties with nonviable pollen, the planting plan shown in Fig. 65 seems even better.

Cherry and plum. It is recommended, both in the East and in the West, that in a new planting at least every third tree in every third row should be planted to the pollinating variety.

It has been shown that in a blooming season of low temperature the yield of Windsor cherry trees 2 rows from the pollinizing variety dropped 38 per cent. Thus the advisability of a pollinizing tree adjacent to every tree to be pollinated is obvious. Furthermore, experience in Oregon showing that a second row is too far from the pollinizing variety indicates that a ratio of 1 tree in 9, or the planting plan shown in Fig. 64, lower, is advisable.

Topworking solid blocks of one variety. Where solid blocks of one variety have been planted, provision must be made for cross-pollination by topworking the trees at regular intervals to the desirable pollinizing variety or varieties. It is suggested that a plan similar to that given in Fig. 64 be followed. This plan gives the minimum number of trees to be topworked as 1 in 9, or 11 per cent. No tree of the main variety is further from its pollinizer than the diagonal distance between tree rows.

In those instances in which the planting to be pollinized consists of a variety with nonviable pollen, two varieties must be topworked into the planting in order to pollinize each other. For example, the varieties Jonathan and Delicious might be used for a solid planting of Stayman Winesap. A suggested plan is shown in Fig 66. In this planting the distance of a tree from its pollinizer is no more than two rows.

Temporary provisions for cross-pollination. Until permanent arrangements, such as topworking, have produced a source of effective pollen, temporary provision for cross-pollination must be made. Several methods have been suggested of which the first two are commercially practicable:

1. Introduction of bouquets of flowers of effective cross-pollinating varieties.
2. Hand cross-pollination.
3. "Bee pollen coater." [16]

Introduction of bouquets. For some time past bouquets of bloom taken from suitable pollinizing varieties have been introduced into apple, pear, and sweet cherry orchards. Where the procedure has been put into practice with care and thoroughness, and where the supply of pollinizing insects was abundant it has proved quite successful.

The bouquets should not be placed in the planting until the flowers are opening on the trees. Large branches last longer than small ones. They should include flowers with dehiscing anthers as well as flowers about to open. This insures a supply of pollen for the greater part if not the entire period of bloom. Experience indicates that the bouquets should be placed in the trees (and not immediately adjacent to the hives). Satisfactory results have sometimes been obtained when containers for bouquets were placed between the rows and off the ground. In an 8-year-old heavily blooming Bartlett pear orchard in Ohio 1 bouquet in a 2-quart Mason jar to a tree was found to be effective. Usually if the bloom is properly selected refilling is unnecessary. As many bouquets as possible should be used in large apple trees; in a solid McIntosh planting in New York pollination was localized in the immediate vicinity of the bouquets, during a cool rainy season. This method obviously requires strong colonies of bees. Otherwise its success is doubtful. (Fig. 67.)

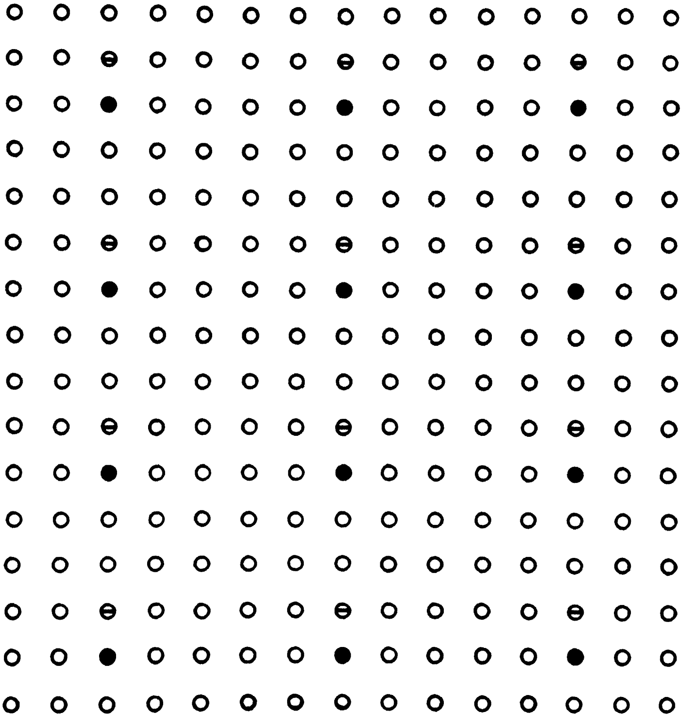

Fig. 66. Suggested plan for topworking a variety which has nonviable pollen. The two varieties in the pollinizing row must have viable pollen. This is the minimum number of pollinizing trees suggested.

Hand cross-pollination. Recently hand cross-pollination has been practiced on a commercial scale in the Pacific Northwest.[91] It has been adopted particularly to insure a set of fruit in Delicious and Winesap orchards. It was suggested by MacDaniels [68] that this method be generally used when insect activity is inadequate and the supply of bloom for bouquets limited. In New York it considerably increased the yield of McIntosh trees in a 16-acre solid block with one hive of bees per acre and a few pollen bouquets distributed throughout the orchard.

Flowers open, or about to open, are collected and the anthers removed by rubbing the flowers over a No. 12 wire screen. After the pollen is dried at room temperature which usually requires 24 to 48 hours, it is placed in bottles and applied by a long-handled camel's hair brush. It is applied to the stigmas of one or two flowers in a cluster which are "spaced" as they would be after thinning. It

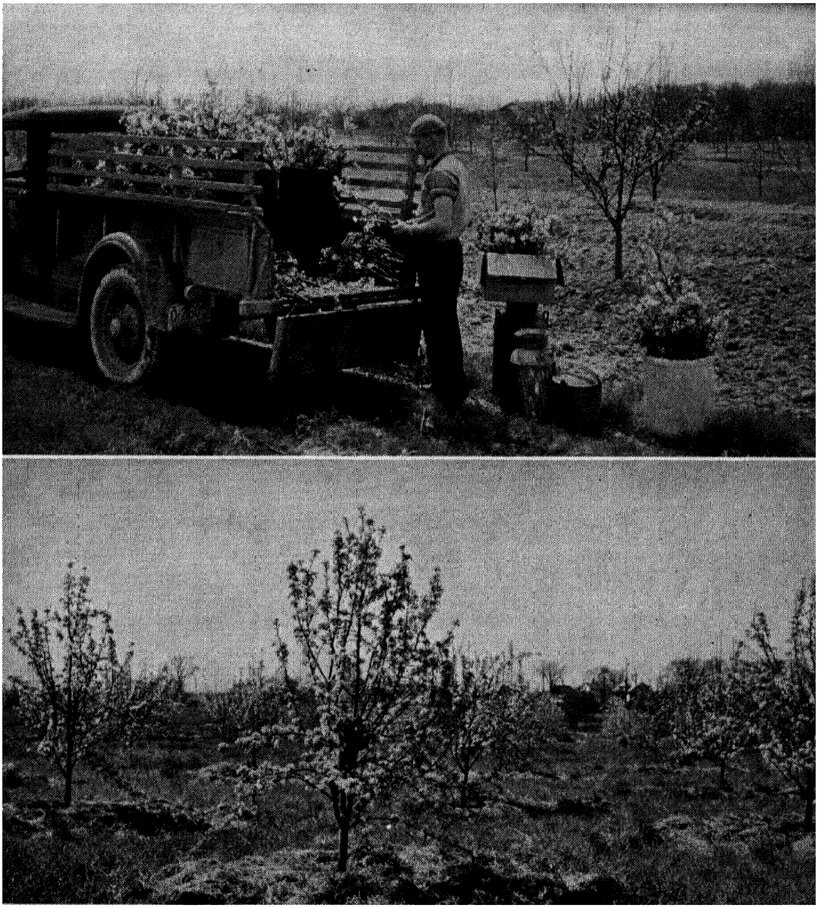

FIG. 67. Preparing bouquets of bloom for introduction into a young Bartlett pear orchard (upper). Bouquets in place in tree (lower).

is reported that 1 out of 4 flowering spurs on a 20-year-old apple tree can be pollinated in an hour, with a total cost per tree of 30 to 35 cents.

Where the method has been used in the Pacific Northwest it is stated that ½ ounce to 3 ounces of pollen are required per acre at a total cost of $2.00 per ounce. In the West 400 ounces of pollen were used to 175 acres of orchard at a total cost per acre, including pollen and its application, of $15.00. Those who have used this method point out that it is merely a makeshift until provision can be made for permanent cross-pollination. The practice theoretically avoids the necessity of fruit thinning.

Excessive cross-pollination. In seasons favoring bee activity it is quite true that excessive pollination may take place under the current recommendations. Undoubtedly when the yield exceeds a full commercial crop, cross-pollination has been excessive, and yet it is very difficult, if not impossible to so control pollination that no more than a definite amount of fruit is produced. Weather conditions which may develop during the blooming season cannot be predicted in advance, and the arrangement of pollinizing trees established at planting necessarily predicated unfavorable conditions.

It is probable that in the future more stress will be placed upon controlling the extent of cross-pollination, but practicable provisions have not yet been established. Possibly in some instances where wild insects are abundant, fewer colonies of bees may be introduced. In other orchards growers may withdraw the colonies after one or two days of weather favorable for bee activity. In the latter instance the bees must be removed a mile or more from the orchard. It is probable, however, that the grower will still be forced to provide for more than a full commercial crop, thus removing the overload by thinning. It is to be hoped, however, that some future provision will afford increased control of fruit setting.

Grape. Cultivated grape varieties may be classified as follows in regard to flower structure: [87, 105]

1. Perfect hermaphrodite—flowers with functional stamens and pistil.
2. Pistillate—flowers with stamens short and reflexed or bent. Pollen sterile, pistil highly functional. This type classifies as an imperfect hermaphrodite.
3. Staminate—flowers having rudimentary pistils with functional stamens. Seedless or nearly seedless varieties belong in this group.[105]

One of these three types of flowers exists in all the different varieties. American native species bear staminate and pistillate flowers on separate vines, while most European varieties produce only hermaphroditic flowers. The majority of grape varieties, however, have hermaphroditic flowers and are thus self-fruitful.[7, 11]

The following varieties have reflexed or recurved stamens while some possess sterile pollen. Consequently they are self-unfruitful. Those with sterile pollen are obviously ineffective as pollinizers.

Amber Queen
Banner
Bakator
Barry
Black Eagle
Brighton
Eclipse
Eumelan
Gaertner
Herbert
King Phillip
Lindley
Massasoit
Merrimac
Moyer
Pontiac
Salem
Vergennes
Wilder
Wyoming

Cross-pollination of varieties is presumably brought about largely by air currents. The New York Station recommends that the pollinating variety should be planted within 16 feet of the varieties to be pollinated. This recommendation is based on the distance which pollen is presumably carried by air currents. Grapes are apparently very unattractive to bees.

Muscadine grapes. Varieties of the muscadine grape (*Vitis rotundifolia*) such as Scuppernong, James, Mish, Flowers, Thomas, Memory, Hopkins, and Eden are self-unfruitful, due to the fact that the flowers have sterile pollen (vines are imperfect hermaphrodites).[3, 84] All of the so-called perfect-flowered wild Muscadine grapes are also pollen-sterile. Vines with fertile pollen, termed "mules" (possessing rudimentary pistils) are used for pollination and fertilization. Such vines planted for pollination purposes, should be known to bloom at the same time as the varieties to be pollinated. It is recommended that in a commercial planting every third vine in every third row be planted to a staminate vine. Small mining bees (*Halictus*) are considered the most useful pollinizing agents, although it is recommended that honey bees be placed in the vineyard as well.

Strawberry. Cultivated strawberry varieties are classified in two groups based on the types of flowers produced.[24] The first type, called the perfect or hermaphroditic, is characterized by both functional pistils and stamens. The second type possesses only functional pistils and is termed pistillate or imperfect. However, even the perfect-flowered varieties frequently produce some flowers with functional pistils only, depending upon environmental conditions during the previous fall.[24]

The imperfect-flowered varieties are:

Big Late
Bubach
Cardinal
Columbia
Glen Mary (semiperfect)
Haverland
Howard Supreme
Huxley
Minute Man
Meyer
Oberschlesien
Paul Jones
Rice
Sample
Tardive de Leopold
Warfield

Environmental conditions may reduce the viability of pollen in varieties normally producing perfect flowers and thus result in malformed fruits or "nubbins." Usually the flowers which bloom earliest are affected. Glen Mary, classed as semiperfect, may occasionally produce little or no viable pollen, particularly on the earliest-blooming flowers.

Imperfect varieties are now rarely planted. When one is desired, 1 row of a perfect-flowered variety should be planted to 5 or 6 of the imperfect-flowered. When two varieties, one imperfect and one perfect, are used in equal numbers, the 2 varieties are usually alternated, 3 of each being used together.

Blackberry and Dewberry. The self-fruitful blackberry varieties are: [107]

Ancient Briton
Blowers
Early Cluster
Early Harvest
Early King
Eldorado
Illinois
Kenoyer
Miseareau
Minnewaski
Ward
Snyder

The following dewberry varieties are self-fruitful:

Cox
Dallas
Lucretia
Mayes
Ruth

The Oregon Evergreen, loganberry, youngberry, and Boysenberry are self-fruitful.

The following dewberry or blackberry-dewberry hybrids are reported to be self-unfruitful:

Cazadero
Chestnut
Haupt
Lime Kiln
Mammoth dewberry
Manatee

McDonald
Muchee Grandee
Premo
Rogers
San Jacinto
Sorsby
Spaulding
White
Wilson

The Burbank Thornless is self-unfruitful.

Self-unfruitful varieties are usually planted in such a way as to alternate 2 rows of one variety with 2 rows of another in order to produce effective cross-pollination.

Raspberry. Black Raspberry. Cumberland, Gregg, Kansas, Plum Farmer, and Black Pearl are reported to be self-fruitful.[107] Observations indicate, however, that bees or naturally pollinizing insects are essential for proper fruit development.

Purple Raspberry. Varieties of the purple raspberry such as Columbian are considered self-fruitful.

Red Raspberry. Cuthbert, King, Marlboro, Lloyd George, Latham, and Antwerp were found to be self-fruitful.[42] These tested varieties also showed a high degree of cross-fruitfulness, except in the case of Cuthbert pollinated by Latham, a combination which produced a considerable number of fruits with few seeds. Insects are also valuable in the self-pollination of the red raspberry.

Gooseberry. Gooseberry varieties are reported to be self-fruitful, although in North Dakota, Perry is reported to be self-unfruitful.[121] Tests indicate that open pollination produces more seeds per fruit and that insects are useful in distributing pollen.

Currant. All currant varieties have been found to be sufficiently self-fruitful if insect pollination is provided. A lack of pollinizing insects to aid in self-pollinizing will result in extreme berry abscission.

Blueberry. In general, tests with the blueberry indicate that provision should be made for cross-pollination.[6, 76, 100, 119] Although in Michigan,[76] Adams, Cabot, and Pioneer are considered self-fruitful, it appears in general, that for maximum crops of large-sized fruit the varieties should be interplanted.[100] Two rows of one variety followed by 2 of another is the usual recommendation. Provisions should also be made for insect pollination.

Pollinizing Insects

Since the pollen of the various tree fruits is carried by pollinizing insects rather than by air currents,[14] these insects are obviously essential in the case of self-unfruitful varieties. Furthermore, it has been found within recent years that their introduction has greatly improved fruit development in both the self-fruitful tree and small fruits. In fact it seems especially desirable to introduce colonies of bees into small fruit plantings in order to increase the number of perfectly developed berries. This was found to be particularly true in Michigan with the Cuthbert red raspberry and the Cumberland black raspberry. The set of the sour cherry is also favorably affected by the same means.

The pollinizing insect of most value for all types of fruit is the honey bee (*Apis*) but wild bees, including bumble bees (*Bremus*) and solitary bees belonging to the genera *Halictus* and *Andrena* are also valuable.[49, 93, 94] Large numbers of Syrphid flies (*Diptera*) are frequently found in fruit bloom and to some extent, though in a minor way, aid in pollination. The presence of wild bees usually depends upon the proximity of woods, waste, or untilled land. If such insects as bumble bees and solitary bees are absent or few in number, colonies of honey bees must be introduced. In most fruit-growing regions this is an established practice.

Effect of environmental conditions upon bee activity. Various environmental conditions such as air temperature, wind velocity, and rainfall are of outstanding importance in affecting the activity of pollinizing insects. When these conditions are unfavorable, the insects make short flights and their activity is decreased, which reduces the set of fruit. It is for this reason that varieties must be planted relatively close to their pollinizers.

Temperature. Air temperature greatly affects bee activity. Experiments show increasing bee activity as the temperature increases from 42° F. to 90° F. Studies in New York [120] indicate that the strongest colonies show appreciable activity even at temperatures ranging from 42° F. to 50° F., but it is known that below 57° F. honey bees cannot maintain their activity for more than a short period. Bee activity is greatly increased between 60° F. and 70° F.; the best flights do not occur until the temperature reaches 65° F. and for full flight it is reported that 70° F. is required.[93] If other conditions are favorable, an abundant set of fruit may be obtained even though the temperature during bloom does not reach 70° F.

Wind. In some localities wind is the outstanding factor limiting pollination. Bee activity is at a maximum when the air is still but may show little reduction with a wind of from 1 to 2 miles an hour.

With increasing air movement the activity is reduced, and is greatly retarded at a velocity of about 15 miles per hour. Activity ceases altogether at 25 miles per hour.[93]

Rainfall. Rainfall prevents the activity of bees almost immediately, but they may be fairly active with high humidity.

Ratio of colonies to acreage. The ratio of colonies to acreage is an empirical matter and depends obviously upon several factors of which the strength of the colony and the number of wild pollinizing insects in the vicinity are the most important. The size and age of the trees, and the amount of bloom are relatively unimportant. Whether or not a variety is self-unfruitful is an obvious factor in governing the number of colonies to be introduced into the planting.

Strength of the colonies. The strong colony is valuable because of the greater number of bees available under unfavorable weather conditions. The best possible strength, according to Phillips,[93] is 13 to 14 frames of brood in 2-story hive bodies. The amount of brood at the time of fruit bloom is roughly indicative of the number of adult bees. Before bloom a 3-story body may need to be added. The 2-story overwintered colony containing 6 or more frames of brood and 4 pounds of bees is the minimum strength recommended. Fruit growers should insist on strong colonies and rent bees only from reliable keepers.

Phillips [93] concluded that one colony of the maximum strength was sufficient for 4 acres of mature trees, while one colony of minimum strength was only one-fourth as effective and should be distributed at the rate of one to each acre. Brittain [14] concluded from Canadian studies that one colony of bees was capable of pollinating sufficient flowers on several acres of orchard to produce a full commercial crop.

Obviously the younger the trees and the lighter the bloom, the smaller the number of pollinizing insects required. With young bearing trees, one colony for 8 to 10 acres may be sufficient in a favorable blooming season.

Pollinizing insects in the locality. On certain fruit farms, particularly in such regions as southeastern Ohio and West Virginia, a sufficient number of wild insects may be present to thoroughly pollinate the various fruits. Under such circumstances introduction of honey bees is not only unnecessary but also unwise since cross-pollination might prove excessive.

Sprays injurious to bees. Observations in Canada [14] show the most sudden and complete mortality among bees following the application of sulphur-lead arsenate in dust form. Sulphur dust is also reported to cause some injury and death but the extent is unknown. The greatest poisoning occurred as a result of applying lead arsenate just previous to and just after the main bloom.

Many plants other than the trees themselves may serve as sources of poison when it is applied in the orchard during bloom. To involve the least difficulty the bees should not be placed in the orchard until the early varieties are just coming into bloom, and should be taken away before the calyx spray is applied.

Chromosome Constitution of the Variety

The chromosomal constitution of a variety is an important factor affecting the set of fruit. This is particularly true with the tree fruits,[21, 22, 50, 59] and is also important in determining the form and development of the small fruits.[22] This effect upon fruit development is due to the fact that the chromosome constitution affects the distribution of chromosomes in the meiotic divisions, as previously discussed at the beginning of this chapter.

Varieties which possess an even-numbered multiple of the basic number of chromosomes have viable pollen and egg cells (with the exception of certain hybrids) and the plants themselves are usually highly fertile and productive. On the other hand, the varieties with odd-numbered multiples of the basic number tend to produce microspores and megaspores with widely varying chromosome numbers. As a result, many of these spores because of their aberrant number, either fail to develop further, or the pollen and egg cells produced are sterile. Others, although capable of effecting fertilization, form embryos or endosperm which eventually abort. In some instances, the embryos tend to develop only slightly while others give rise to seeds which are either nonviable or produce weak seedlings. Since fruit development is so dependent upon fertilization and subsequent embryo development these plants with odd-numbered multiples are not only of no value as pollinizers for other varieties, but they are frequently less fertile and productive even when pollinized with varieties possessing fertile pollen.[50]

Numerous examples can be given of the effect of the chromosome constitution upon the fruiting behavior of horticultural plants. Such apple varieties as Arkansas (Mammoth Black Twig), Tompkins King, and Rhode Island Greening, as a result of their triploid chromosome constitution, show very high pollen sterility as well as considerable degeneration occurring in the meiotic divisions on the female side or during the development of the female gametophyte.[55, 59]

In some of these triploid varieties the amount of sterility of the female gametes may reduce the fruitfulness of a variety to such a degree that it is no longer commercially desirable. The apple variety Arkansas (Mammoth Black Twig) is of this type. The same relation of chromosome number to fruit behavior is shown in some of the raspberry-blackberry hybrids developed in England in which the basic number is 7.[22] The Mahdi berry, a triploid variety (21 chromosomes), develops only occasional drupelets. On the other hand, the veitchberry and the Himalaya berry, tetraploids with 28 chromosomes, are much more productive. The loganberry with 42 chromosomes (hexaploid) is productive while the laxton berry, a heptaploid with 49 chromosomes is again relatively unproductive.

Hybrids of the native species of plums and such species as *Prunus salicina* (Japanese plum) and *Prunus Simonii* also tend to show considerable sterility of both the male and female elements due to the fact that their hybridity results in irregular distribution of chromosomes at meiosis.

Fungal, Bacterial, and Insect Injury

When the pedicels are infected by apple scab (*Venturia inaequalis*) severe abscission of flowers and immature fruits may occur. Furthermore, fire blight (*Bacillus amylovorus*) also results in loss of immature fruits. Brown rot of stone fruits (*Sclerotinia cinerea*) is also detrimental to fruit development.

Injury by various kinds of insects including codling moth (*Carpocapsa pomonella*), bud-moth (*Tmetocera ocellana*), leaf-roller (*Archips argyrospila*), plum curculio (*Conotrachelus nenuphar*), rose-chafer (*Macrodactylus subspinosus*), green fruit worm (*Xylina antennata*), and blister beetles (*Meloidae*) may result in abscission of flowers or immature fruits. Partially developed fruits will not always abscise, however, unless the seed cavities are invaded.

Injury by Spray Materials

Caustic sprays of lime sulfur, in case they produce visible injury to the foliage, may reduce the set of apples. Furthermore, experiments indicate that lime sulfur solution of the dilutions 1 to

40 and 1 to 60 may cause some fruit abscission, even if the foliage shows no visible injury.[56] Spray solutions of this strength need not reduce fruiting below the equivalent of a full commercial crop in the case of heavy-setting varieties, but with lighter-setting varieties, these solutions may prove commercially detrimental.

Within recent years considerable attention has been given experimentally to the effect upon the set of fruit of various materials applied to the flowers during bloom.[70, 72, 73] Lime sulfur applied as a spray,[70] or sulfur as a dust reduced the set to below the equivalent of a full commercial crop when applied to flowers just before, and just after (24 to 48 hours) they were pollinated. Application of these materials after a 48-hour period, favorable to pollination, did not reduce the set appreciably, if at all. With the lighter-setting varieties, such as Stayman Winesap, Delicious, and McIntosh, a period of effective pollination should be insured before spraying. Bordeaux mixture 1-3-50 and 20-80 copper lime dust applied the day before or the day after did not reduce the set.

On the basis of present evidence, Bordeaux mixture, copper-lime dust, and wettable sulfur sprays may be applied during bloom without reducing the set below a full commercial crop, since even though they may result in some flower abscission, all the flowers in a cluster do not open at the same time.

Abscission Periods in Tree Fruits

The abscission of flowers and partially developed fruits subsequent to bloom, is not ordinarily continuous, but proceeds in more or less definite waves. The period elapsing from petal fall to the first wave and between successive waves depends upon several factors, namely, the species of fruit, variety, occurrence of fertilization, position of flower, vigor of the plant, and the prevailing weather conditions.

Apple. Two abscission periods are usually recognized, one termed the "first drop" beginning shortly after petal fall and continuing for 2 or 3 weeks, and the other the so-called "June drop."[25, 47, 52, 54] The June drop begins a few days after the completion of the first drop and continues from 2 to 4 weeks. It should be kept in mind that the term "June drop" is somewhat of a misnomer since in certain regions the second wave of abscission begins in May and is completed in June. In other regions it begins in June and is completed in July. With many varieties the first drop usually consists of greater numbers than the second. However, on the basis of weight, the second drop is usually heavier since it is comprised of partially developed fruits of progressively larger size.

The time at which the abscission of an individual flower or partially developed fruit occurs is related to the number of ovules fertilized and the stability of the embryos produced. If fertilization does not occur in any ovule, the flower usually abscises shortly after petal fall with the receptacle unenlarged as compared to the full-bloom stage. With 1, 2, or 3 ovules fertilized the receptacle shows slight enlargement and the time of abscission is delayed more or less in proportion to the number fertilized. The first drop, as above considered, includes the flowers in which no fertilization occurred and those in which 1 to 3 ovules were fertilized, but with no more than a slight enlargement of the receptacle. Murneek in Missouri prefers to divide the unenlarged and the slightly enlarged individuals into 2 drops rather than 1.[82] It is certain that if 2 such drops are considered, they overlap.

On the other hand, in most varieties the so-called June drop is separated from the first drop by several days in which few or no individuals abscise. The fruits which fall in this drop are progressively larger, and again the size attained depends somewhat upon the number of ovules fertilized. This drop, however, is largely an expression of the competition between fruits on an individual spur or cluster base. The effect of competition for food material is demonstrated by the fact that the number of fruits falling in the June drop is usually inversely proportional to those which abscised shortly after petal fall. If the first drop was light the second drop is frequently heavy. When the first drop is heavy, the second (June) drop is lighter. The varieties Baldwin, Grimes Golden, Oldenburg (Fig. 68), Wealthy, Yellow Transparent, and Rome Beauty usually show a light first drop, the later drop being somewhat heavier. If, on the other hand, the first drop is abnormally heavy, the second will be lighter and at times even negligible. Other varieties such as Stayman Winesap, Arkansas, Delicious, Rhode Island Greening, Tompkins King (Fig. 68), and Winesap normally have a heavy abscission shortly after bloom, while the later abscission is usually light.[50, 52, 53] This heavy abscission in Stayman Winesap and Rhode Island Greening is in part associated with their triploid constitution which has resulted in instability of the embryos and their tendency toward a retarded growth and degeneration.

Pear. Two periods of abscission were observed at East Malling Station in England in the varieties Doyenne du Comice, Conference, and Pitmaston Duchess. A very heavy, early drop of nonfertilized flowers occurred, followed, after an interval of 2 weeks, by a slight second drop of partially developed fruits.[104]

Peach. In general, two main waves of abscission are observed in the peach, although the second may consist of several minor crests.[9] The first drop begins immediately after full bloom and extends over a period of from 2 to 3 weeks. It involves flowers having aborted pistils, those which have not been pollinated and fertilized, and possibly a small percentage in which fertilization occurred but the zygote or embryo aborted. The later period affects partially developed fruits in which embryo and endosperm development has taken place and whose size increased as the season advanced. Harrold[43] divides this latter period into 2 drops (called the second and third) beginning the fifth week after full bloom. It is probable that partially developed fruits fall in several waves depending upon weather conditions such as rainfall. In fact it has been observed that immediately following rain and wind, a rather large amount of abscission occurs which would normally have taken place more evenly, over a period of several days.

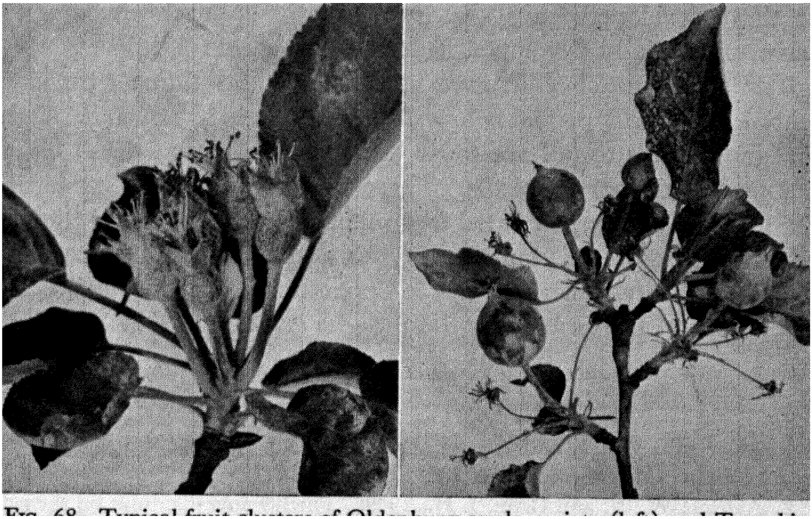

FIG. 68. Typical fruit clusters of Oldenburg apple variety (left) and Tompkins King (right) after the first drop. Note normally heavy abscission in Tompkins King as indicated by the flowers still attached to the cluster base.

Cherry. Abscission[13] in the sour cherry is reported to occur in three distinct waves. The first wave affects those in which the ovules are shriveled, indicating either that no fertilization has occurred, or that the zygote aborted immediately. The second and third drops consist of partially developed fruits in which the embryo and endosperm have degenerated.

Plum. The abscission affects flowers which showed no enlargement after full bloom, and partially developed fruits showing a wide range in size. The latter group varies from those only slightly enlarged to plums of small to medium size. Dorsey [26] reported that the plum has 3 waves of abscission as follows: first, flowers with aborted pistils falling immediately after bloom; second and third, partially developed fruits. In Delaware [25] two or three abscission waves of partially developed fruits were observed

The actual number of waves observed in the plum seems unessential; they will probably overlap considerably. In general the first individuals to fall are those flowers which reached full bloom but possessed aborted pistils. These are followed in succession by the normal, but unpollinated and unfertilized flowers, and those in which the zygote or young embryo aborted. The final abscission affects individuals of varying size depending upon the stage of development of the embryo at the time its growth ceased.

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11

FRUIT THINNING AND ALTERNATE BEARING

General Principles of Thinning

History. The practice of thinning fruit is by no means a modern development, but like many other agricultural practices the time and place of its origin are not definitely recorded. Pomological writers for several centuries have considered it desirable and recommended its use. In his *Treatise of Fruit Trees* published in London (1768), Thomas Hitt wrote,[20] "When there is too great a quantity of fruit suffered to remain upon any part of a tree, it is not so good as if there were only a proper quantity left on; and sometimes a tree becomes weak by bearing too plentifully. . . ."

"Fruits are thinned the best either with a very narrow, pointed pen knife or scissors; for by nipping them off with the thumb and forefinger, those designed to be left on are often displaced, as also the young branches and leaves. . . . Though I advise to thin fruit at different times, yet it should not be done later than the month of May; for if they are suffered to grow pretty large they rob one another, and none should be left on so near together as to touch before they be full-grown; for they are apt to throw each other off or at least to spoil their shapes. Besides, they never come to the size they would otherwise do, and large fruits when ripe are always the best flavored. . . ."

The same ideas, enlarged and elaborated by other writers, have been repeated in subsequent works on fruit culture. Both early and modern authors, however, generally refer to the following points: that thinning as a practice increases the size and appearance of the fruit; that it is presumably valuable in maintaining annual bearing, and that it prevents tree breakage due to overbearing.

Definition. Thinning is defined as the removal of a portion of the fruit crop from a plant before maturity, in order to prevent overbearing and to improve its general marketability.

Physiological basis of thinning. In the last analysis, the physiological basis for the practice rests upon the fact that fruiting is an exhaustive process. This statement is borne out by experience, and various experiments, including chemical analyses, verify this conclusion.[6, 7]

The production of flowers and fruits inevitably removes a considerable amount of the various carbohydrate materials, organic nitrogenous substances, and essential nutrients from the spurs and other vegetative portions of the plant. The various cultural practices of the grower are designed, in reality, to maintain within the plant a sufficient supply of those materials which further growth, flowering, and fruiting. In particular, a large, efficiently functioning leaf surface is found to be essential to the development of an adequate supply of carbohydrates. Otherwise the plant becomes devitalized to the point at which it not only produces an inferior product, but is also increasingly susceptible to disease and low-temperature injury.

In addition to chemical investigations which demonstrate the exhaustiveness of fruiting, other experiments show that the growth of the vegetative portions, such as shoots and leaves, is usually less during the year of fruiting than during an unproductive year. A considerably greater growth of these vegetative parts occurs at a time when material formed by the leaves is not diverted into flowering and reproductive channels.

The growth of fruits is a more exhaustive process than is the development of flowers.[6, 7] Flower development undoubtedly removes a considerable amount of carbohydrates and nitrogenous substances,[23] but if the flowers fail to set fruit the supply may be replenished in a relatively short time. On the other hand, the production of fruits utilizes the nutrient supply over a longer portion of the growing season. In fact, the food materials may be so exhausted during a very fruitful year that almost no vegetative growth occurs at that time and thus the differentiation of flowers may be largely or wholly prevented.

Objects of Thinning

Not all objectives of thinning are equally important with respect to each kind of fruit and its varieties, but in general, thinning tends to produce the following results:

1. Increased size of the remaining fruits.

2. Increased color.
3. Improved dessert quality.
4. A decrease in total yield.
5. Less limb breakage.
6. Maintenance of tree vigor by reducing the exhaustiveness of fruiting.
7. More regular flower production in response to early thinning.
8. Removal of diseased and insect-injured specimens.
9. Labor reduction at harvest.

The favorable effects of thinning are definitely the result of a more favorable relationship of leaf surface to fruits. Within recent years experiments have been conducted in which fruits were thinned according to varying ratios, as for example, 20, 30, 40, or 50 leaves per fruit. These experiments, initiated by Magness and Haller,[16] invariably indicated that a curtailed leaf-surface per fruit (in the apple, 10 or 15 leaves) results in fruit of small size, poor color, mediocre quality, and finally excessive exhaustion of the fruit plant. The number of leaves per fruit, which normally occurs before thinning in the case of such heavy-setting apple varieties as Grimes Golden and Jonathan, may actually be only 15 or less,[11] but experiments indicate that as the leaf-fruit ratios increase, the desirable fruit characteristics increase also.

In connection with thinning experiments it has been found that leaves several feet from a fruit (up to 10 feet, depending on the variety) are nevertheless effective in producing increased fruit size, providing of course that no other fruits intervene.[17] Fruits were influenced by leaves above or below, even on separate branches.

Effect upon Size of Fruit

The chief immediate advantage of thinning is the increase in size attained by the remaining fruits. This is well verified by experimental work with the apple,[3, 11, 33] pear,[1] peach, [14, 26, 42, 44] and grape.[45] Obviously the size attained must be calculated in accordance with the number of fruits which remain on the tree after thinning, rather than on the number removed. Typical data showing the relationship between number of leaves (leaf area) and size of fruit, in the apple and peach, are presented in Tables 22 and 23 respectively. The fruits were grown on ringed branches to prevent downward translocation of material away from the fruiting points.

With an increase in the number of leaves per fruit the size increased, a result which was particularly apparent when the number of leaves was increased to 30 per fruit, or approximately one fruit to 100 square inches of leaf area.

With both the apple and peach the increase in size was greater, proportionately, in response to the first small additions in leaf area, than in response to additional increases. In other words the increase in leaf area gradually reaches the point of diminishing returns. This does not signify reduction in the photosynthetic activity of the leaves as their number per fruit increased, but indicates rather a greater utilization of nutrients by the vegetative organs (as the requirements for fruiting were satisfied).

TABLE 22. THE RELATION OF LEAF AREA TO SIZE OF APPLES (GROWN ON RINGED BRANCHES)

(From Magness, Overley, and Luce) [33]

Variety	*Number of Leaves per Fruit*	*Average Area of Leaves Sq. In.*	*Size of Fruits at Maturity*		*Approx. No. per Box*
			Volume cc.	*Diameter Inches*	
Delicious	10	2.65	131.4	2.50	200
	20	2.89	167.4	2.70	163
	30	3.02	225.5	2.90	118
	40	3.15	227.2	2.90	118
	50	2.89	227.2	2.90	118
Jonathan	10	3.22	141.6	2.55	188
	15	3.30	167.4	2.70	163
	25	3.31	199.0	2.80	125
	40	3.44	216.1	2.86	120
Rome Beauty	10	4.13	180.7	2.75	150
	20	3.75	248.7	3.05	105
	30	4.24	313.9	3.30	92
	40	4.57	361.1	3.50	82
	50	4.53	352.0	3.45	84
Winesap	10	2.31	122.6	2.40	210
	20	2.37	178.2	2.75	150
	30	2.47	204.6	2.90	127
	40	2.54	222.0	2.95	117
	50	2.49	213.0	2.92	122

Similar results have been obtained in Ohio, on unringed branches.[11] However, in order to approximate more natural conditions, representative branches were thinned to spacings ranging from 6 to 14 inches. All leaves on each branch were removed at

TABLE 23. THE RELATION OF NUMBER OF LEAVES TO SIZE AND QUALITY OF PEACHES. VARIETY ELBERTA

(*From Weinberger*)[44]

Number of Leaves per Fruit	*Leaf Area per Fruit Sq. In.*	*Gain in Volume cc.*	*Per Cent of Fresh Weight*			*Acidity*[a]
			Dry Weight	*Reducing Sugars*	*Total Sugars*	
5	34	46.3	12.07	1.88	5.39	46.4
10	68	68.7	12.39	2.24	7.61	49.2
20	136	89.8	12.73	2.37	7.56	48.1
30	204	90.7	11.80	2.16	7.46	44.5
40	272	110.1	12.62	2.18	7.50	44.7
50	341	119.4	14.35	2.41	8.80	47.2
75	511	133.8	14.66	2.43	9.04	51.6

[a] Acidity expressed as number of cc. 0.1 *N* NaOH required to neutralize 50 grams extracted fresh tissue.

harvest, counted, and the total leaf area measured electrometrically. The number of leaves corresponding to each spacing is given in Table 24.

TABLE 24. SPACING DISTANCE AS RELATED TO NUMBER OF LEAVES PER FRUIT, LEAF AREA AND SIZE OF FRUIT. VARIETY GRIMES GOLDEN

(*From Ellenwood and Howlett*)[11]

Thinning Distance	*Leaves per Fruit*	*Leaf Area per Fruit*	*Average Area of 1 Leaf*	*Average Weight per Fruit at Harvest*	
				Marked Branches	*Entire Tree*
	No.	*Sq. In.*	*Sq. In.*	*Oz.*	*Oz.*
Unthinned—1[a]	15.5	37.6	2.43	2.95	2.81
6-inch—2	30.4	56.1	1.85	3.65	3.14
8-inch—2	31.7	62.9	1.98	3.56	3.34
10-inch—1	47.1	78.4	1.66	4.23	3.51
12-inch—2	34.3	100.9	2.94	4.22	3.67
14-inch—1	56.0	127.6	2.28	4.88	4.73

[a] Number of trees from which leaves were removed.

The number of leaves per fruit on the unthinned tree was 15, corresponding to only 38 square inches of leaf area. On the other hand at the 6 and 8 inch spacings, the distances commonly used in commercial practice, there were 30 to 31 leaves per fruit, or 56 to 63 square inches.

Apart from the number of fruits maturing, other factors influence the size of fruit, namely:

1. Age of tree. Usually with increase in age a tendency toward reduction in fruit size occurs. This is an important factor with the Wealthy apple, for example.

2. Apple varieties that are naturally small-fruited, such as Early McIntosh and Winesap, require more thinning than those characteristically large.
3. The more vigorously vegetative growth usually produces fruit of larger size.
4. Fruits are larger under favorable water conditions.
5. Pruning during the dormant season or previous to fruiting usually increases size.
6. Sprays which greatly reduce the photosynthetic efficiency of the leaf tend to reduce size.

Effect upon Color of the Fruit

Thinning fruit tends to increase the amount and intensity of the overcolor of the apple (Table 25) and peach. The effect on the overcolor is the result of the development of anthocyanin, a pigment formed from less complex carbohydrate compounds. In addition it usually increases the intensity of the yellow undercolor on red-fruited varieties.[17]

TABLE 25. DEVELOPMENT OF RED OVERCOLOR ON SURFACE OF APPLES IN RELATION TO LEAF AREA PER APPLE

(From Haller and Magness)[17]

Leaves per Apple	*Percentage of Surface Having Red Color*					
	Ben Davis (1925)	*Delicious (1925)*	*York Imperial (1926)*	*Ben Davis (1926)*	*Baldwin (1927)*	*Jonathan (1927)*
0	—	—	—	0	0	3
5	21	—	14	22	3	32
10	43	33	39	26	7	38
20	47	38	43	34	41	40
30	55	44	47	22	26	64
50	52	66	49	21	14	66
75	41	47	28	20	18	69

The ground color of the fruit was determined by comparison with the standard chart of the United States Department of Agriculture.[31] Color No. 1 is a green corresponding to that found on very immature fruits, while 4 is nearly a full yellow with only a very slight tinge of green. The colors 2 and 3 are intermediate. The data in Table 26 show a gradual increase in yellow coloring in response to leaf increase up to 30 per fruit. Very little change takes place in response to more than 40 leaves in Grimes Golden or with more than 50 in the other varieties.

TABLE 26. GROUND COLOR [a] OF APPLES ON RINGED BRANCHES IN RELATION TO LEAF AREA PER APPLE

(From Haller and Magness)[17]

Leaves per Apple	*Ground Color*					
	Grimes Golden (1925)	*Delicious (1925)*	*Ben Davis (1925)*	*York Imperial (1926)*	*Baldwin (1927)*	*Jonathan (1927)*
0	1.6	—	—	—	1.0	1.7
5	1.9	—	2.6	2.0	1.4	2.0
10	2.2	2.7	3.0	2.1	1.7	2.2
20	3.3	3.2	3.2	2.0	2.4	2.3
30	—	3.3	3.3	2.9	2.5	2.8
40	3.8	—	—	—	—	—
50	—	4.0	3.4	2.8	2.3	3.1
75	—	4.0	3.6	3.4	2.4	3.1
80	3.7	—	—	—	—	—

[a] Values in table obtained by averaging the numbers 1, 2, 3, 4 according to shades given in text above.

Thinning, however, does not affect color as strikingly as size. For example, Palmer and Fisher concluded after 16 years of tests that the influence of thinning upon the development of the red overcolor was slight and inconsistent.[36] Thinning Jonathan in Ohio had far less effect upon color than pruning.[11]

The result is partly due to the fact that coloring of the greatest amount and intensity requires not only leaf surface per fruit (affected by thinning) but also exposure of the fruits to sunlight (affected by pruning).

In fact the production of color is so greatly influenced by other practices, that the effect of thinning is complicated and not always in accordance with expectation. For example, in York Imperial the color reduction brought about by applications of nitrogen fertilizer was so great, that thinning, even to 50 leaves per fruit (heavy), did not increase the color to a degree equalling that found on unthinned trees which had had no nitrogen application.[13] Only by a thinning equivalent to 100 leaves per fruit was the unfavorable effect of nitrogen on the overcolor counterbalanced.

From a practical viewpoint, the value of thinning for its effect upon color alone is related, under Eastern conditions, to the premium paid for that quality. The color standard for apples in the U. S. No. 1 grade is not sufficiently high to necessitate the practice with this object alone in mind.

Effect upon Dessert Quality

The chemical composition of the fruit is decidedly influenced by thinning. In the apple, [17, 33] pear,[33] peach,[26, 35, 44] and grape [45] increased leaf area increases the proportion of those materials associated with a higher dessert quality.

The dry matter and total sugars in the fruits increases up to a certain point with increased leaf surface. This result is due largely to increase in sucrose. Although the acidity also tends to rise with increase in leaf surface, this change is less consistent than that which occurs in the case of total sugars. In general, about 30 leaves per fruit were required for apples of good dessert quality, a somewhat higher number being required for the Delicious apple which has a peculiarly characteristic flavor which is undesirable at the lower leaf areas.

Effect of Thinning upon Yield

Thinning usually reduces the total yield of the various fruits,[1, 3, 14, 42, 44] although if light, this does not invariably follow.[43] It is true, however, that commercial thinning usually reduces the total yield, more or less in accordance with the results indicated by the various experiments. Such a result is to be expected since the practice is obviously designed to decrease competition by removing sufficient fruits to permit the remainder to benefit by the increased food materials.

The important point is the extent of the reduction. Obviously a heavy crop requires more thinning than a light crop. The practical objective is to grow the largest crop commensurate with certain quality standards. Apple fruits attaining a diameter of 2½ inches are considered a marketable size. Oversized fruits may be an indication that the tree has been overthinned, and in any case their quality is slightly inferior, they are not always as successfully stored, and they are frequently more susceptible to physiological disorders. (Chapter 14.)

Effect on Limb Breakage

Many varieties of the different fruits set so heavily that they must be propped or thinned to prevent breakage. Even propping may not always prevent this difficulty. Thinning, however, has reduced the amount of limb breakage and almost entirely obviated the use of props in the orchard.

Effect upon Regularity of Fruit Production

Experience indicates that thinning the apple at the usual time, after the June drop, has had little or no effect upon *changing* an alternate bearing habit to the annual bearing condition.[3] Evidence now indicates that the practice was completed too late despite the rather wide spacing adhered to.[32] Possibly this late thinning may have a slightly accumulative effect in *maintaining* an annual bearing condition, for after 16 years of thinning tests McIntosh and Yellow Newtown showed a greater tendency to become alternate with a light (3-inch) and a medium (6-inch) spacing than with heavier thinning.[36] In general, however, trees quite frequently develop the alternate bearing condition despite efforts to prevent this.

Although thinning after the June drop has usually failed, either to maintain or bring about annual bearing in the apple, experiments have shown the very favorable effect of thinning the varieties before the June drop.[2, 17, 18, 32] Thinning within 4 weeks subsequent to full bloom induced the development of sufficient flowers for a full crop the succeeding year in a number of apple varieties including Delicious, Jonathan, Rome Beauty, Stayman Winesap, Yellow Newtown, Yellow Transparent, and York Imperial. In these experiments, thinning was extremely heavy as indicated by the ratio of 1 fruit to 100 leaves.

Obviously this ratio is equivalent to much less than a full commercial crop during the year of thinning. The longer the thinning is delayed after bloom, the less pronounced its effect. Although varieties differ somewhat, results indicate that, while flower formation for the succeeding year's crop can be affected from 60 to 90 days after full bloom, the percentage which can be influenced after 40 days is much less. The thinning of normal trees so as to produce sufficient flowers for the succeeding year's crop should, in fact, be done within 30 days after full bloom. Local conditions such as high sunshine may vary this recommendation, but, in general, where alternate bearing is to be modified, early thinning is necessary.

The response of Elberta peaches to early thinning was found to be favorable at a time when flower formation and set, induced by the dry season of 1930, was extraordinarily heavy.[38] Recent experiments with Elberta in New York also show that early thinning greatly increased the yield the following year.[42]

Thinning for Removal of Disease and Insect-Injured Specimens

In thinning, fruits that have been injured by insects or diseases, as well as poorly-shaped specimens, should be removed. In the peach and plum the amount of such disease as brown rot (*Sclerotinia cinerea*), is greatly reduced by the spacing due to thinning. Furthermore, spray solutions will more effectively cover the fruits if they are not densely clustered.

Such a procedure naturally cannot hope to have eliminated all defective fruits at harvest time. However early-season elimination of cull fruits is one of the somewhat intangible but actual benefits. When apple scab is very serious early in the year, thinning provides an opportunity for eliminating many of the scab-deformed fruits. Thorough spraying early in the year reduces the amount of defective fruit to be removed at thinning time.

Effect upon Reducing the Labor of Handling the Crop

The effect of thinning in decreasing the labor of handling excessive crops of small-sized fruit is a factor of commercial consequence. There are no exact figures showing the additional cost of handling small fruits, otherwise removed; but it is obvious that the reduced cost at harvest partially compensates for the cost of thinning.

Relation of Thinning to Moisture Supply

The most noticeable reponse to thinning occurs under conditions of deficient soil moisture. In fact, where water supply is frequently a limiting factor, thinning becomes practically imperative with the apple, pear, and peach. Moreover, it is particularly essential in the case of those apple varieties, such as Grimes Golden, York Imperial, and Wealthy, which, after the last drop, still retain several fruits per cluster.

In North Carolina, peaches having a leaf-fruit ratio of 90, but grown on trees planted in dry plots, were smaller than fruits on irrigated trees having only 30 leaves per fruit—a fact which indicates the reduced efficiency of leaf surface under a low moisture supply.[25] This relationship between moisture supply and size and quality of fruits must encourage those practices which, by lowering the demand for moisture, increase the supply. The converse of the recommendation is also true; under favorable moisture conditions the effects of thinning upon size and color may be slight.

Relation of Pruning to Thinning

Experience indicates that pruning and thinning are interdependent. Since both practices increase the size of fruit, one tends to obviate the other.[11] Thus if a tree is already invigorated by pruning, the thinning requirement is lessened. Both practices may be effectively used as long as they are carefully related. Obviously the pruned tree, drastically thinned, would undergo an excessive reduction in yield. Of the two practices, thinning receives the greater emphasis at present. Inasmuch as pruning reduces the bearing surface, and is not so easily governed as the alternative process, it should be kept at the minimum consistent with its other favorable effects, and the excess fruits removed by thinning.

Nitrogen-Carrying Fertilizers in Relation to Thinning

Nitrogen-carrying fertilizers have a directly adverse effect on fruit color. In addition, by increasing the set of fruit and decreasing the leaf-fruit ratio, they also tend indirectly to reduce both size and color. To entirely counterbalance this reduction in color, it is necessary to thin to a degree so heavy as to be impracticable.[13] In practice, then, it would seem feasible to thin the apple for the purpose of maintaining the desired size and quality of fruit and to reduce limb breakage, but not primarily to increase the color. The color can be increased in a more practicable manner by reducing the amount of nitrogen-carrying fertilizer applied, together with proper pruning.

THINNING SPECIFIC FRUITS

The Apple

Apple thinning in the East has never attained the status of peach thinning, since those regions producing fruit for wholesale markets have not generally adopted the practice. In certain Eastern areas, where large size and highly colored fruits are required for special retail markets, for roadside or special urban trade, thinning is a regular practice.

After 30 years of intensive apple production it now seems evident that those varieties which are either small-fruited, or tend to show a heavy set at the end of the June drop, usually require thinning. Early McIntosh, Grimes Golden, Golden Delicious, Wagener, and Wealthy belong in the latter category. Thinning may also prove desirable with other varieties, but for other reasons. In the case of Delicious and its bud mutations, a large leaf area per fruit is an essential factor in inducing high flavor and dessert quality generally. Other varieties, such as Stayman Winesap and Jonathan, may require thinning in some seasons, despite the fact that they have only one or two fruits per cluster after the June drop. Obviously this recommendation is dependent upon the number of fruits which survive this drop and should be definitely related to the amount of pruning. In those regions where light pruning of mature trees is particularly emphasized, thinning is usually more frequently practiced in order to maintain size and quality.

Time to thin. Theoretically, the sooner the thinning is completed following bloom, the more favorable its effects. Obviously the drain upon food materials is immediately reduced, with an accompanying increase in flower formation, for the subsequent year's crop. Furthermore, within limits, at least, the earlier the thinning, the larger the fruits at harvest. Considered from a practical viewpoint, however, fruits of the fall and winter varieties are not usually thinned until after the June drop fruits can be readily distinguished. The earlier thinning is time consuming, and thus too expensive to offset the increased size. On the other hand, due in part to their relatively short growing season, as well as to their heavy-setting proclivity, Oldenburg and Yellow Transparent respond quite favorably to an earlier thinning.[11] Growers not infrequently thin the varieties by merely removing and marketing the first fruits that ripen. Consequently many small-sized Yellow Transparent fruits are found on the market, early. Earlier thinning would increase the size if this result seems desirable. In that case the fruits to be left must be carefully selected for size, in order to eliminate those likely to abscise later and thus cause too great a reduction.

If the grower plans to establish annual bearing in certain varieties, thinning should be completed no later than 4 weeks after petal fall, since later thinning will not produce sufficient flowers for the succeeding year's crop.

Amount to thin. There is no disagreement in respect to the objective of thinning—namely, a properly productive ratio between leaf area and fruits. The difficulty lies rather in the realm of practical attainment. The general recommendation which specifies 30 leaves to a fruit is excellent theory, but is open to the practical objection of counting or estimating leaves and fruits. Recommendations based on minimum distance between adjacent fruiting points also present certain difficulties, but until a more practical index becomes available, the latter method seems best. The use of this index is open to misunderstanding. It does not, of course, refer to fruits adjacent to each other, on separate limbs or branches. The distance involved is from spur to spur or twig to twig along the same branch. According to the usual practice the various fruiting clusters are thinned to one fruit each, as the first phase of the operation. If further thinning is required the clusters permitted to bear fruit to maturity are then "spaced," that is, separated from each other by removing all fruits which intervene within a specified distance or "space."

Recently the "graduated space" method has been suggested as an alternative to the more usual method termed "uniform space." [15] The graduated method is in reality a modification of the "uniform," which involves a spacing more or less the same throughout the entire tree. According to the "graduated space" method the fruit is thinned more severely on the inner portion of the tree, while fruits at the periphery are allowed to hang more closely. Presumably this method allows for differences in the individual branches, in their vigor, productivity, and exposure to light. In a Michigan experiment, the total number of fruits removed by the graduated-space method was somewhat less than the total removed uniformly. Both types, however, reduced the yield of undesirably small fruits, and resulted in other favorable effects, including the net cash return.

In general, the spacing distance recommended ranges from 6 to 10 inches. The latter is considered a heavy thinning and probably is preferable only with the varieties of the Delicious group, or under those conditions where large size seems particularly desirable, despite the greater reduction in marketable yield. A spacing distance of 6 to 8 inches on heavily set trees is better adapted to ordinary conditions, although this too will vary in accordance with the variety and vigor of the tree.

In varieties such as Rome Beauty, Stayman Winesap, Turley, Rhode Island Greening, Delicious, and McIntosh reduction of the spurs to one fruit each is probably the extent of the thinning required, particularly under Eastern conditions. On the other hand, Wagener, Wealthy, Grimes Golden, York Imperial, Oldenburg, Winter Banana, Yellow Transparent, Golden Delicious, and Baldwin usually require some additional spacing of the fruit-bearing clusters.

It is also possible to make use of the fact that fruits after the June drop show about the same size relative to each other as at harvest time. Thus experience enables the grower to distinguish those fruits which in all likelihood will not grow to a size of 2½ inches. All such fruits are removed, thus eliminating the breaking of clusters or spacing. This method approximates a very light thinning and is applicable only when the moisture supply is fairly reliable, since it might easily lead to overbearing and too small fruit if water should become quite deficient later in the season.

In practice, the well-informed grower will probably use more than one method in a judicious combination best suited to his own particular requirements. The salient points of thinning practice are: Removal of all small, insect- or disease-injured specimens; removal of all but one fruit to a cluster; a spacing distance which will allow for sufficient leaf area per fruit without inducing an adverse crop reduction.

Methods of thinning. Fruit may be thinned either by hand or by using a pair of light shears. In removing the fruit by hand, the exertion should be sidewise rather than direct, so as to avoid displacing other clusters or spurs and weakening the apple left. While the use of shears slows up the work from 10 to 15 per cent, and may have a greater tendency to bruise the other fruits, it is nevertheless preferable to use shears for short-stemmed varieties or those which tend to set in clusters. They are advantageous also for late thinning when it is difficult to separate apples from the cluster base.

Cost of thinning. The cost of thinning apples depends upon the speed and hourly wage of the worker. The number of fruits an average workman will remove in an hour ranges from 400 to 1,500 depending upon the varietal characteristics, the size and shape of the tree, and the agility of the workman.[3, 11] It ordinarily takes 1 man 2 to 3 hours to thin a heavy crop on the average mature tree. Obviously the heavier-setting varieties, or large trees which necessitate the use of ladders, will consume more time than others.

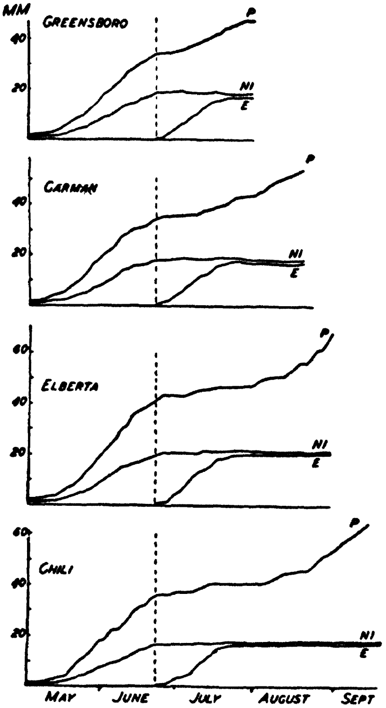
The Pear

Experience has shown that it is comparatively easy to overthin the pear; since, in general, it is less productive than the apple, the commercial effect of overthinning is much more pronounced. In Oregon[1] thinning Beurré d'Anjou to 50 leaves per fruit, as opposed to 35 on the unthinned trees, showed a considerable reduction in yield, while even a light thinning of Bartlett pear proved unprofitable. Winter Nelis, however, definitely profited by the increased size of fruit on the thinned trees.

Thinning the clusters of vigorous trees to 1 fruit each is usually the maximum amount desirable, in case thinning seems necessary at all. Where growth conditions are particularly favorable, some clusters may retain 2 fruits. Should additional spacing seem necessary, a 4- to 6-inch distance is usually sufficient.

The Peach

Since peach trees are inclined to heavy bearing and its unfavorable consequences, the practice of thinning has become well established in most regions. The flowering habit is responsible in part for this tendency toward excessive bearing, for in spite of the fact that pruning removes part of the flowers, the tree will often develop more fruits than can be satisfactorily matured. Thus from the salability angle, thinning is practically a necessity, unless the premium paid for the fruits of large size and good quality is not such as to counterbalance the decreased yield.

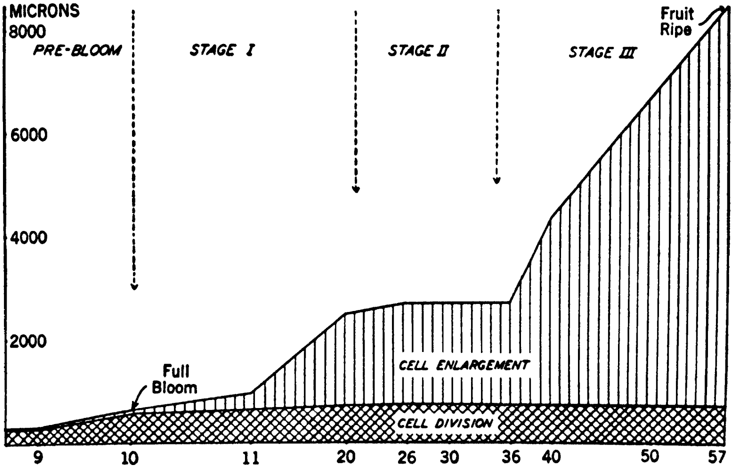


(*Courtesy H. B. Tukey, New York Agr. Exp. Station, Geneva.*)

FIG. 69. Growth curves of pericarp (*P*), nucellus and integuments (*NI*) and embryo (*E*) of four varieties of peaches ripening at different seasons. Period of each from full bloom to ripening.

Time to thin. Peach trees are usually thinned as soon as the fruits likely to fall in the last drop can be readily distinguished. Extensive investigation shows that fruits thus thinned, even up to within 4 or 5 weeks of harvest, will show a markedly favorable effect upon size.[9, 10]

Such an outcome results from the nature of the development of peach fruits. In this (Fig. 69) as well as other stone fruits (Fig. 70), stages of growth are based upon the enlargement of the various parts.[5, 9, 40, 42] In Stage I which occurs immediately after fertilization, the size of the pericarp increases rapidly.[42] Following this period, the rate of growth of the fruit itself is considerably retarded, although the embryo within the seed increases in size very rapidly (Stage II). From this time on, until maturity, the fruit undergoes a rapid enlargement of the flesh, often called the "final swell" (Stage III) (Fig. 70). A large proportion of the moisture and solids contained in the flesh at maturity are translocated to the fruit during this final period[29]—a fact which accounts for the pronounced effect produced by thinning, even though the operation takes place only a few weeks before harvest. By reducing the intense competition which normally occurs between unthinned fruits during the "final swell" both size and quality are greatly improved.



(Courtesy H. B. Tukey, New York Agr. Exp. Station, Geneva.)

FIG. 70. Increase in thickening of the ovary wall in the sour cherry from prebloom to fruit ripening showing the amount due to increase in number of cells and amount due to cell enlargement.

The period which intervenes between full bloom and the beginning of Stage III is not the same for all varieties. The greatest variation occurs in the length of Stage II. Data typical of both early- and late-ripening varieties, and showing the number of days required for each stage of development, are given in Table 27.

TABLE 27. DAYS REQUIRED FOR THE THREE STAGES OF DEVELOPMENT OF THE PEACH FRUIT

(*After Tukey*)[40]

Variety	*Days Required to Complete Each of the Three Stages of Development*			
	Stage I Days	*Stage II Days*	*Stage III Days*	*Total Days*
Greensboro	50	5	36	91
Triumph	49	9	42	100
Carman	52	10	51	113
Elberta	53	35	36	124
Chili	50	42	52	144

It is to be noted that a later date of ripening is primarily accompanied by the prolongation of Stage II, while Stage III also is shorter, in the case of the earlier-ripening varieties. It should be stated here that different latitudes produce some variation in the length of each period, although the relation between varieties remains very nearly the same. For example, in New Jersey in 1925 the length of the growing season of Elberta was 139 days; 52 for Stage I; 43 for Stage II; and 44 days for Stage III.[5]

From these data it is evident that thinning Elberta within 6 to 7 weeks of harvesting will insure that competition between fruits is reduced before the beginning of the "final swell." The beginning of Stage III does not usually occur until at least a week after the last of the immature fruits have fallen naturally.

It is true also that the size of fruit can be influenced by environmental treatments during the first period of growth.[8, 25, 44] Irrigation experiments in North Carolina show that peach fruits grown in dry plots were considerably smaller at the end of the first stage. Cullinan has also obtained data indicating that the very early varieties such as Mayflower, Cumberland, and Greensboro because of their unusually short-growing season, respond to an earlier thinning 3 weeks after bloom.[8] Probably June Elberta, Marigold, and Golden Jubilee would show a similar response. On the other hand, for those varieties which ripen later than Golden Jubilee thinning just before the beginning of the "final swell" is generally recommended.

In case of an exceptionally heavy bloom, early thinning does result in greater flower formation for the subsequent year's crop, but only very rarely does it seem wise, in view of the added expense and time involved.

Amount to thin. As usual, specific circumstances determine the degree of thinning; varietal differences, tree vigor, and the premium paid for large fruits, are always influential. Greensboro and Belle of Georgia, whose fruits are naturally small, must be thinned accordingly. The thinning distance generally recommended is from 6 to 8 inches. This spacing constitutes a medium thinning, while 3 to 4 inches is light. Both are subject to modifications which fit the immediate circumstances. The possibility of thinning fruits to a given number for a tree of a given size is advocated in certain regions. Such a recommendation is dependent upon previous experience as an indication of the approximate number necessary, so that its success lies chiefly with the individual who uses it.

The vigor of the tree, particularly as influenced by pruning, must be taken into consideration in the amount of thinning required to produce fruits of the desired size and quality. The pruning and thinning practices must be particularly well correlated in the peach, if this goal is to be attained. If light pruning is practiced, a heavier thinning is by necessity required; if the pruning is moderate to heavy, a somewhat lighter thinning is mandatory if an excessive reduction in yield is not to be experienced. Growers must make the needed adjustments to suit their own particular conditions of soil, water supply, and market demands.

The Plum

The efficacy of thinning plums depends upon the species, variety, and set of fruit. The Japanese varieties are characterized by a very low leaf to fruit ratio. It is reported in South Africa that the Kelsey plum actually produces more fruits than leaves. In consequence of a heavy set, the brown rot fungus easily spreads and, furthermore, limb breakage frequently occurs.

Lombard, a variety of the European group (*Prunus domestica*) showed a definite improvement in the market grade of its fruit and a favorable effect upon subsequent growth and fruiting, in response to the practice.[43]

Whenever the set is heavy thinning seems advisable, but the price especially in the East makes the practice questionable, unless limb breakage or diseased fruit would result otherwise.

Like the peach, the plum varieties show the most pronounced growth in green weight and greatest increase in dry matter during the "final swell." In view of this fact, thinning just previous to this stage would be expected to produce practically as favorable effects upon size and quality as an earlier thinning.[28]

The Apricot

Thinning apricots to a spacing of 2 and 4 inches proved to be of little value in British Columbia.[12] Furthermore, the location of the fruits on the tree seemed to be an important factor governing size; those on the outer branches were considerably larger than those growing in the shaded portions of the trees which were vigorous and well pruned.

The apricot shows the three stages of development described for the peach.[27] In the Royal and Blenheim varieties the first 2 periods were 6 weeks each in length, and the third, 4 weeks. Heavy thinning during the first period and during the "final swell" increased the rate of growth appreciably; the second stage was unaffected.

ALTERNATE BEARING

The production of crops in alternate years is termed *alternate* or *biennial* bearing, and is the result of no flower formation in response to heavy yields during the "on" or bearing year. This condition which is quite common with many apple and pear varieties is not limited to these pome fruits, for certain varieties of the stone fruits fail occasionally to form flowers, due to the production of an excessive fruit crop.

In the East frost is the most outstanding immediate factor which affects annual bearing. In case the frost kills practically all the flowers or young fruits, excessive differentiation occurs for the succeeding year's crop.

Varietal aspect. Varieties may be classified in accordance with an inherited tendency toward alternate flower formation. The varieties ordinarily considered as distinctly alternate in their habit are Baldwin, Oldenburg, Wealthy, Wagener, Yellow Newtown, Yellow Transparent, and York Imperial, while Golden Delicious may very quickly develop this tendency. Exceptional trees of these varieties often occur and may bear more or less annually, although the difference between production in the "on" and "off" years may still be quite pronounced.

Those varieties which show a pronounced tendency toward annual flower formation are Ben Davis, Gallia Beauty, Rome Beauty, Gano, Twenty Ounce, Stayman Winesap, Willow Twig, and Winesap. Exceptions occur here also and individual trees have been known to bear alternately for years.

A third group tends to bear more or less annually, with rather heavy crops followed regularly by light to moderate production. Whenever the yield is excessive in any one year, the tendency toward alternation immediately becomes pronounced. Among these varieties are Delicious, Northwestern Greening, Grimes Golden, Jonathan, McIntosh, Northern Spy, Rhode Island Greening, Stark, and Winter Banana.

Morphological aspects. The following include the more important morphological aspects of alternate bearing.[30, 37, 39]

1. It is to be primarily understood that alternate bearing may develop following a heavy crop, even in varieties which have not definitely inherited this characteristic. Varieties which do have such an inherited tendency, such as Baldwin, may develop the habit even with the first crop which may be relatively light. In fact, a tree may tend to alternate whenever it produces a heavier crop than usual, even though its bearing surface is comparable with adjacent trees of the same age. This condition may develop even in trees of Stayman Winesap and Rome Beauty, although usually trees of these varieties do not alternate until they have become somewhat devitalized by several successively heavy crops.

2. Trees of varieties which tend to bear annually differentiate a much greater proportion of their flowers on shoots than spurs. Rome Beauty, for example, characteristically produces most of its flowers on shoots, while the decidedly alternate varieties such as Wealthy, tend to differentiate flowers largely on spurs. Other varieties fail to classify in either extreme, and form their flowers both on shoots and spurs.

3. The yearly growth of spurs and shoots has little apparent effect upon alternate flower formation. During the "on" year few spurs and shoots of any length will differentiate flowers while in the "off" year, all but very weak spurs form flowers. This situation minimizes the value of practices designed to induce annual bearing by increasing the length of those organs. Only very weak spurs fail *continuously* to form flowers.

4. Uniform or annual production may be the result of the flowering and fruiting of various portions of a tree, or of alternation in the flowering of the spurs.

In case they mature fruits, only a very small proportion of the spurs or of the shoots arising laterally from the cluster base will form flowers.

An annual bearing tree is one in which a more-or-less equal proportion is maintained between spurs and terminals which set fruit and those which do not, since flowers are usually formed only on those units which do not mature fruits.

Whether branches on a tree behave as units depends somewhat upon the variety. Greater individuality in the reaction of both branches and spurs is found in varieties inclined to annual bearing. Less individuality of branches and spurs is shown in Baldwin,[39] in which one fruiting spur or terminal may prevent flower formation on several adjacent spurs. This is shown by the fact that a relatively light crop in this variety tends to prevent differentiation of flowers for the succeeding year.

The following facts are basic to a consideration of the problem: A fruit-bearing spur will not ordinarily form *flowers* at the same time. Moderate fruit setting which also allows for moderate flower formation is the essential factor in the prevention of alternation. An excessive crop in one year produces the negative extreme the next. It is these extremes which must, in all cases, be avoided.

Relation of alternate bearing to cultural treatments. Pruning. Some controversy has arisen as to whether pruning in the "on" or the "off" year is more efficacious in inducing more regular bearing. One theory maintains that pruning in the heavy bearing year, by removing a considerable portion of the flower buds, tends to be of greater value. Acting upon this theory, investigators in New Zealand [19] have removed many spurs which would otherwise have borne and the practice is reported as successful. Pruning, if moderate, may reduce the exhaustiveness of fruiting, yet it does not usually remove a sufficient number of fruits to induce the desired change in habit.

On the other hand, moderate pruning during the "off" or light year has also been reported to induce greater regularity.[21] At one time the belief was current that pruning at this time by inducing strong spur and shoot growth might reduce the proportion of these organs differentiating flowers for the heavy-bearing year. This idea was predicated on the theory that excessive growth would prevent flower formation, a result which occurs almost invariably when young nonbearing trees are stimulated by heavy pruning or fertilization just as they are about to form their first flowers. However, trees which have been bearing for some years do not respond in a manner similar to young trees, and this practice has not, in general, produced the results hoped for. Yet in case a light flowering does occur during the "off" year, pruning, by increasing the set, may possibly reduce the number of flowers formed for the "on" year, since the greater the yield the light year, the more moderate the flower formation for the "on" year. It has been observed that, in comparison with the small number of flowers formed, a relatively large number tend to abscise during the light year.

Application of nitrogen-carrying fertilizers. No fertilizer practice, either as regards time or amount of application, can be relied upon to eliminate alternate bearing.

"On" year treatment. It can be said that evidence is accumulating warranting a reduction in the amount of nitrogen applied just previous to bloom the "on" year. Insofar as such applications increase the set to an unnecessary degree they tend to increase the number of fruits retained during the critical period, usually June and early July, thereby further reducing the possibility of flower differentiation for the "off" year.[22] In the Northwest,[34] for example, applications of nitrogen applied during the spring of the "on" year merely served to increase the alternate-bearing intensity of Yellow Newtown trees. In New York [41] Tukey and Anderson reported the same effect after several years' fertilizer experiments with young bearing trees of the same variety. Applications of nitrogen to vigorous trees either during the previous fall or during the spring preceding the heavy bloom would tend, it is believed, to increase the alternate-bearing intensity.

In those instances where growers have reduced the amount applied to alternate-bearing trees previous to bloom, they occasionally make an after-bloom application. That such applications will prevent trees which carry pronounced overloads of fruits from becoming alternate has not been established. Certainly little evidence is available indicating that it could counterbalance a small leaf-fruit ratio, despite its favorable effect upon photosynthesis. Where growers have thinned somewhat earlier than usual, application in small amounts may possibly stimulate the production of flower buds for the succeeding year. Evidence on this point is necessary before the practice can be based on other than theoretical considerations.

"Off" or light year applications. Applications of nitrogen made during the spring of the "off" or light year presumably serve a twofold purpose. In the first place, it maintains the vigor of the tree, stimulates growth, and provides a sufficient reserve of nitrogen for fruit setting the heavy year. In the second instance, it will increase the fruit set the light year, thereby tending to moderate flower differentiation for the succeeding year. It would seem that, in general, so long as applications are not made immediately preceding the flowering of the heavy year they may have a small, but perceptible, value in maintaining annual bearing.

Means of Reducing or Controlling Alternate Bearing

There is at present no wholly satisfactory means of controlling alternate bearing. The prevention of excessive crops on trees concerned, is all-important, but frequently the condition develops in spite of every precaution. Uncontrollable events such as late frosts and periods of drought during flower differentiation may counterbalance the effect of growers' practices and induce a fluctuation toward alternate bearing. Various suggestions for averting this tendency are briefly considered.

Heavy, early thinning. Heavy, early thinning represents the best means of reducing alternate bearing,[17, 18] although this means is far from satisfactory due to the expense and time involved.

Use of annual-bearing varieties. The use of annual bearing varieties or those having a tendency in this direction offers one means of providing more regular crops. Rome Beauty and Gallia Beauty have been found valuable in this respect, which is one of the principal advantages of Stayman Winesap as well. Such a selection, however, does not fully satisfy this problem since Delicious, Jonathan, and McIntosh, which are very desirable commercially, will alternate following the production of excessive crops.

Prevention of excessive fruit set. Undoubtedly excessive cross-pollination by inducing an excessive crop tends to induce alternate bearing. The excessive crop is accompanied by little or no flower-bud formation for the subsequent year's crop. It has been observed that where small crops were produced as a result of inadequate pollination, the trees, which were not of a distinctly alternating variety, showed a tendency to flower more regularly. However, from a practical viewpoint, it is impossible to limit cross-pollination to the exact equivalent of a full commercial crop. Where the fruit set is constantly heavy, because of favorable environmental conditions and an abundance of bees, the grower might reduce the bee population or remove the colonies after 1 or 2 days' activity. As a general practice, however, this means of regulating fruit set is not reliable.

Protection of leaf surface. Present evidence points to a large, actively functioning leaf surface as a factor of value in maintaining annual bearing. Sprays of the proper dilution and containing the correct materials protect this function. Control of insects and diseases which injure the leaves or cause their abscission is also of supplementary importance.

Deflorating sprays. Destructive chemical sprays may indirectly promote flower differentiation for the succeeding years crop by deflorating the trees during the "on" year, and thus change the bearing year. As yet no spray has been effective in destroying a sufficiently large proportion of the flowers without at the same time greatly injuring the opening foliage. Tar oils,[4] cresylic acid, and the "di-nitro" oils applied at the late cluster bud stage have been reported to be the most promising materials tested. Effective concentrations of tar oil distillate range from 1 to 2 per cent, while the best concentration for the di-nitro oils is yet to be determined. At present it would appear that these materials are more effective in destroying practically all flowers and thus changing the year of bearing than in regulating the crop during the "on" year to an amount requiring no hand thinning.

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12

THE HANDLING AND STORAGE OF FRUIT

A most important period in the life of fruits is that between the time they are removed from the tree or vine and when they reach the ultimate consumer. The care and expense of production may be offset by careless or improper handling, thus making the marketing of the fruit difficult or impossible. The fruit grower has a definite responsibility to deliver his product into the hands of the consumer in the proper stage of ripeness and in its full perfection. All this means a knowledge of the best time of picking, the possession of proper picking and handling equipment, and storage facilities which are economically sound for the unit concerned.

Time of picking and the ripening process. As orcharding becomes more refined there is greater interest in the exact time each variety should be removed from the tree. Harvesting at the convenience of the grower and when labor is available often results in fruit of low quality, both for storage and for the consumer. Fruit that is picked before properly ripened, i.e., "green," is likely to develop such storage troubles as bitter pit and scald, tendency to shrivel, and failure to develop satisfactory dessert quality, while overripe fruit deteriorates rapidly, lacks prime quality, and is subject to soft scald in storage.

In order to determine the best picking date for apples a comprehensive study was made by the United States Department of Agriculture in coöperation with several of the states.[38, 40] The chief changes in the ripening process studied were: (1) increase in size; (2) change of color of seeds; (3) change in color of the unblushed portion of the fruit (under or ground color); (4) development of blush color (overcolor) on red or blushed varieties; (5) progressive softening of the fruit; and (6) change in the tenacity with which the fruit adheres to the tree.

Another criterion of picking time is that of calculating the number of days from full bloom to maturity. From this work it was learned that an apple usually increases in size as long as it remains on the tree. Apples which are picked in early fall increase in weight as rapidly just prior to harvest as at any time during the growing season.

The color of seed-coats is not a reliable index although it has often been used as such. Generally it is several days or even weeks after the seed-coats are brown before an apple reaches proper maturity for harvesting.

Probably the most reliable index of all is the change of the ground color from a leaf-green to a light greenish-yellow. This applies both to red and unblushed varieties. The exact shade of color varies with varieties. However, the Baldwin may drop badly before the ground color changes develop, and this is true of McIntosh, Jonathan, and Cortland. The McIntosh may still be grass green, or slightly creamy white at the end of the storage season.[15] With the advent of red sports the color criterion may be of little value because of its very early development.

The texture of the fruit has often been used as an index of ripeness. The pressure of the thumb on the cheek of the apple served as a rough measure until a mechanical device was invented to give quantitative expression of the same principle. It was found in these investigations that there was a wide range in the rate of softening, and while it is quite useful with pears it has been none too successful with apples. After the apples are in storage, however, it is the best means of determining the rate of the ripening process or storage condition. But even here, a false index of softening or firmness may be obtained. As the fruit becomes less turgid, it becomes slightly spongy and rubbery and often gives an abnormally high reading.

The separation of the stem (pedicel) of the fruit from the spur or shoot is likewise useful in determining the picking date. Most varieties tend to loosen and drop as they become ready to pick. This is not an entirely reliable guide since in some seasons the crop may loosen and drop almost without warning. This situation usually occurs after a very warm period or a cold period followed by a warm one.

The last of the series was that of recording the time interval between full bloom and maturity of the fruit, which seemed to be affected to only a limited extent by growing conditions. Thus, a Jonathan or Baldwin apple seemed mature in about the same number of days in Virginia and New York, although the temperature on the average would be several degrees higher for the growing season in Virginia. The following represent examples of the usual time interval in days required for several varieties to reach picking maturity: McIntosh, 125 days; Cortland, 130; Rhode Island Greening, 130 to 135; Jonathan, 140 to 145; Grimes Golden, 145; Baldwin, 145; Delicious, 145 to 150; Ben Davis, 150 to 155; Rome Beauty, 160 to 165; Stayman Winesap, 165; and Winesap, 165 to 170. For Bartlett pears it is 112 to 118 days.

Certain exceptions and reservations may be noted. When there is a light crop the fruit tends to mature a few days earlier and a heavy crop, a few days later. Extremely warm weather, especially during the 2 weeks prior to harvest will encourage the early dropping of the fruit. An example of this was noted at Ithaca, New York, where in 1937 it took McIntosh 118 days to mature, while in 1938, 136 days were required, thus indicating that this criterion was an unsatisfactory guide for those conditions.[55]

One of the most important advances has been to "color" or "spot" pick. This refers to the practice of going over the trees several times and picking the fruit that is of best color and size, leaving the others to complete their development. This practice is especially valuable with varieties which have a tendency to develop physiological troubles from overmaturity.

Another test of maturity that has received attention is loss of starch from the fruit. If apples are cut transversely midway between calyx and stem prior to ripening and are stained with a weak solution of potassium iodide-iodine, the presence of starch can be readily detected, a familiar technique of microchemistry. When practically all of the starch has been hydrolyzed to sugar this test will reveal the fact. It has not found general usage, however, and, as pointed out by Tiller [57] may actually be misleading with some varieties.

From this analysis it will be seen that no one criterion alone can be used in determining the proper time for the picking of apples, but the experience of the orchardist is invaluable. Ground color, ease of separation from the spur, firmness, soluble solids, and size of fruit are all useful. The best index of rate of softening is the change of pectose to pectin, but the determination requires too long for widespread use, while surface color and color of seeds are of relatively less value.

Gardner, Marth, and Batjer [24] have demonstrated the value of certain plant growth substances (hormones) in preventing the abscission (dropping) of various plant organs including leaves, flowers, and fruits. This fact has been put to practical use in delaying the pre-harvest drop of apples by spraying with dilute water solutions of these chemicals. Of a number of synthetic growth substances tried, two, namely, naphthaleneacetic acid and naphthaleneacetamide, were outstanding in effectiveness. Concentrations of .0005 to .001 per cent, equivalent to 1.9 to 3.8 grams per 100 gallons of spray, resulted in excellent control of dropping. The effective period of the spray applications is only two to three weeks with most varieties. The materials become effective within a day or two after application.

The commercial effect, by increasing color of the fruit and other economic aspects, must yet be determined.

With pears the time of picking has a determining effect upon their dessert and keeping qualities. The pressure tester has proved more reliable with this fruit than with apples and yet it is far from "fool proof."

The Kieffer pear is widely grown but is usually of tough texture, with many grit cells, and of poor quality. But by proper handling prior to storage it becomes of reasonably good quality. By ripening them at 60° F. after they are picked, the highest quality is attained. Temperatures above 65° or below 55° F. result in low-quality fruit. Rate of softening was found to be closely associated with conversion of pectose (protopectin) * to pectin and pectic acid, and both of these changes were most rapid at 60° F. The quantity of stone cells (schlerenchyma) appears to be much less in properly ripened than in unripened fruit. The apparent decrease seems to be due to the breaking up of the clusters of stone cells into small aggregates.[36]

In the ripening process of peaches it has been shown that there is a marked decrease in protopectin as they reach the final soft, ripe condition. In the nonmelting Shipper Cling variety of peach the

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* Pectose or protopectin molecules are composed of chains of smaller molecules of arabinose, galactose, and galacturonic acid similar to the manner that cellulose and starch are composed of chains of glucose molecules. Pectose is insoluble in water but when converted to pectin, as in the ripening of a peach, it is soluble in water. Pectin may be further converted into pectic acid, which swells and forms jelly in the presence of water or into insoluble salts with calcium. Different enzymes are involved in each of these changes.

insoluble protopectin has been found to be over 100 per cent higher when fully ripe than in the melting-fleshed Elberta.[45]

At Vineland, New Jersey, the length of the fruit development period of Elberta ranged from 123 to 144 days, or a variation of 3 weeks. The length of the period was definitely associated with the time of full bloom.[9] The method of judging maturity of peaches is largely by means of the ground or undercolor of the fruit. The undercolor of white peaches changes from green to cream-white, and of yellow ones from green to greenish-yellow or orange-yellow, depending on the variety. The use of a pressure tester is also recommended, although Morris cautions against using it independently of other methods of selecting fruit to be picked.[44]

There is a wide range in the ripening season of sour cherries even within rather narrow limits of territory or even within the same orchard. The growing-season temperature is of great importance in determining the ripening date, low temperature delaying it. Large crops and limited foliage delay maturity and cause uneven ripening, according to Gardner.[22] Rather contrary to the situation with other fruits, nitrogen applications and good culture tend toward earlier and more even maturing of the crop.

Much of the same situation prevails with the development and maturity of plums as is true for most other fruits. They increase in size from 1.5 to 2 per cent daily as they reach maturity. Likewise they increase in color and sugar content as long as they remain on the tree and softening of the flesh is associated with the ripening process.[3]

Sweet cherries undergo a marked increase in size and weight during the ripening period, and premature picking which has been all too common, has robbed the canned product and the consumer of the fresh fruit of much of its potential quality.[29] The decrease in firmness during ripening is less than that manifest by most other fruits, until the period of overmaturity is reached. There is a marked increase in sugars during ripening, in Napoleon, from 10.6 to 18.9 per cent from June 4 to June 25. The time of picking does not seem to affect materially the shipping quality of sweet cherries. Even when allowed to reach full maturity on the trees the fruit held up sufficiently to permit shipment from Oregon to Eastern markets. Notwithstanding these latter facts the time of picking is of as great importance to the sweet-cherry grower as to the grower of other fruits.

A determination of soluble solids is widely used in California for determining the picking time of grapes, and with good satisfaction.

Factors influencing the storage qualities of fruits. Wallace [62] has summarized the factors which influence the storage of fruit, and most of the items are as applicable to American as to English conditions. "The factors which predestine the storage qualities of fruits may be grouped as follows:

"(a) Materials—including the class of fruit, varieties, rootstocks (in the case of the tree fruits), age of the tree.

"(b) Environmental factors—these may be further divided into two subgroups.

"1. Natural conditions—including the climatic factors of rainfall, temperature, sunshine; soil factors embracing chemical, physical, and biological properties; parasitic organisms such as pests, fungi, etc.

"2. Artificial factors—or factors introduced by the grower. These include soil treatment, cultural operations, and manuring; control of pests, fungal and bacterial organisms, etc.; manual operations on the tree such as pruning, thinning, ringing, time of picking, and handling of the fruit subsequent to picking.

"The storage qualities of fruits are a complex of these factors and since, in considering any one of our three main storage points, certain of these factors act in a similar direction, whilst others exert conflicting influences, it will be seen that the problems are extremely complex."

Considering the last factor mentioned above, that of handling the fruit subsequent to picking, the following must be considered by the grower:

1. Promptness with which it is placed in storage;
2. The temperature and humidity of the storage, as well as the uniformity of these factors;
3. The composition of the atmosphere and its movement within the storage;
4. The presence of gases other than carbon dioxide, such as ethylene and volatile esters given off by fruits;
5. Influence of a wrapper; and
6. The type of packages in which it is stored.

Effect of delay in storage. Since the softening or ripening process of fruit is determined almost entirely by the storage temperature it is evident that a delay in storage at the usual autumn temperatures speeds it up. All varieties of apples have been found to soften with great rapidity at 70° F. Even such varieties as Winesap and York Imperial, though hard when picked, were in prime eating condition within a few days. Softening proceeds about twice as fast at 70° as at 50°, while at 50° it is almost twice as fast as at 40°, and at the latter temperature it is fully twice as fast as at 32°. About 25 per cent longer time was required for fruit to ripen at 30° as at 32°.[40]

Carrick and Goodman, expressing it on a respiratory basis, state that an apple would keep 19 days at 32° F. as well as it would 1 day at 86°, and 2½ days at 32° as well as 1 day at 50°. [15]

Many of the same conclusions were drawn from experiments conducted in New Hampshire. The treatment the apples received during the month following picking greatly influenced their storage life. The McIntosh is the leading commercial apple in New England, and the studies dealing with it are of importance where that variety is grown. It was found that a delay of 5 days in the harvesting, grading, packing, and transportation operations did not materially lower the storage quality, if the fruit was marketed by March 1. But a delay of 10 days reduced the storage life of the fruit 8 to 10 weeks, and 20 days caused it to become overripe and possess no storage value. Fruit that is to be marketed shortly was found to be best if placed in common storage, while that marketed later will be best if kept in cold storage from the first.[50]

Bartlett pears held under temperatures of 65°, 53°, and 43° F. showed little softening until from 6 to 18 days after harvesting. Under storage conditions the commercial life of the fruit was limited to 30 days at a temperature of 43° F.; 60 days, at 36°; and 100 days, at 31°.[39]

Allen, *et al.*,[3] have shown that plums harvested at the usual maturity for Eastern shipment and held for 12 days at 43° F. softened approximately as much as did similar lots held for only 6 days at 52°; after 12 days at the higher temperature a considerable proportion had softened and colored to such an extent as to be considered overripe. Fruit held at 43° F. was usually in good market condition.

The point for emphasis is that the fruit is a living organism when it is removed from the tree and continues to carry on metabolic processes although the activities no longer result in increase of size but rather in the utilization of the stored substances within the fruit. The cells of the flesh remain alive until they die from lack of respirable materials, decay, freezing injury, or by other causes.

Relative humidity. This term refers to the per cent of saturation with water at any given temperature. When the air is saturated the relative humidity is 100 per cent. If the temperature of the air is lowered the holding capacity of the air for water is lowered and condensation or "sweating" takes place. If fruit is held in a dry atmosphere it will shrivel or wilt and its usefulness and appearance are reduced. Too great a humidity favors blue mold and other organisms.

The exact optimum for the various fruits is not known, but a humidity of 85 to 90 per cent is the accepted practice. In common storages it is often necessary to sprinkle the floor; especially is this true if the floor is of concrete. Special spray devices are also used to humidify the atmosphere, and the fruit itself is often sprayed with water.

Temperature. The effect of temperature upon the ripening process is by far the most important single factor in the storage of fruit.

The exact temperature that is optimum for each fruit has been determined by different workers, but there is lack of agreement. Varieties and kinds of fruits undoubtedly vary in their requirements, and environmental factors other than temperature play varying roles with different fruits.

The point at which apples will freeze seems always to be below 30° F. "Several hundred determinations show the following range in variation of freezing points in three common New York varieties."[15] (Table 28).

TABLE 28. FREEZING POINT OF APPLES (DEGREES F.)

Variety	*Lowest*	*Highest*	*Average*
Baldwin	27.21	28.92	28.24
McIntosh	27.32	29.32	27.91
Tompkins King	27.37	28.80	28.08

The most usual temperature recommended for apples is 31° to 32° F. throughout the season, or as near 32° F. as is possible to obtain in an air-cooled (common) storage. For Bartlett pears it is 30° to 31° F. Because of disease, physiological disturbances, and varietal differences there is some disposition to raise the storage point to 35° or 36° F. where apples are not to be stored for their maximum period, but marketed throughout the early part of winter. This is also an important factor for those who build cold storage houses on the farm. The cost of obtaining 32° F. and 35° and 36° is quite different.

Origin of Handling Bruises of Apples

Bruises or other mechanical injuries which occur in the harvesting operations often account for a high percentage of cull or otherwise off-grade fruit. Dropping or throwing fruit, even hard-ripe specimens, is all too common and represents a needless reduction in quality. While a portion of this injury may occur after it leaves the hands of the producer, much of it can be laid at his door. With the advent of grading and washing machines and elaborate packing houses, apples, in particular, are exposed to more opportunities of bruising than formerly. Certain types of packages also cut or bruise the contents unless cushions, paper liners, or other provisions are made to prevent it.[30, 53]

Gaston [23] conducted a survey which showed that 15 per cent of the cull apples was due to bruises. Lack of size and limb rubs were the only other factors which caused a higher percentage.

Analyses of the source of the bruising have been made and they serve as a guide to the grower as nothing else could do. The factors involved were largely: (a) variety; (b) individuality of pickers; (c) type of picking containers; (d) type of field container; (e) the handling and pouring of fruit from one container into another; and (f) the washing and grading machines.

Ellenwood found a small percentage (1.5) of bruising of apples on the trees from wind whipping and limb bruising.[19] The human element, as would be expected, is an important factor in handling bruises, since some individuals are much more careless than others. In the Ohio experiment the speediest picker bruised about 10 per cent of the apples so badly that they were taken out of the first grade. The second one bruised 6 per cent, while the third one, only 3 per cent, in the picking operation. Overholser [46] found that one inexperienced picker out of a crew of 14 had 97 per cent of Winter Banana apples free of any mechanical harvesting injury while an experienced one had only 43 per cent free, indicating that the mere fact of experience is no guarantee.

Emptying the picking receptacle into the field container was an important source of bruising, constituting 50 per cent of all bruising in one test. Overholser found less bruising from the use of 20-quart pails, and a rigid metal canvas drop-bottom picking container than from canvas bags. Round oak baskets lined with canvas are often used for the more tender varieties. Growers of fancy fruits in England as well as America often require the pickers to wear cotton gloves and lay each fruit into the container, without pouring the fruit at any time.

But the most serious sources of damage were that of the washer, the sizing machine, and packing bins. There are three general types of washing machines in use, (1) the flotation washer, (2) the flood or spray machines, and (3) the underbrush machines. In the New York test the flotation washer resulted in 41 per cent bruised fruit and the underbrush, 63 per cent. In addition, the drier device which is used to remove water after washing and rinsing, resulted in considerable bruising, especially of tender or ripe apples. The grader or sizer as well as the bins into which the apples are conveyed after sizing were the greatest offenders of all. One investigator advocates the elimination of chain sizers and conveyors. The spool sizer was not so objectionable, the rapidly revolving kickoff pully caused less bruising, and the use of gradually diverging V-sloping belts gave the least bruising of any of the machines. The use of endless belts resulted in the least bruising of any method. The use of sponge rubber padding on the machinery and more careful handling is greatly to be desired.[26]

In parts of New York state and elsewhere many growers use no regular sizing equipment with McIntosh because of bruising. The fruit is passed along on endless belts or it is handled on canvas covered frames where the sorters both size and grade the fruit by hand.

The important conclusion in all storage investigations is that fruit should be free of skin breaks, stem punctures, bruises, and decay. Blue mold is reported as accounting for about 75 per cent of all apples that rot in storage and the fungus does not gain a foothold in sound fruit.

Sun Coloring of Apples

It has long been noted that when apples (of a red variety) were piled in the orchard at harvest time those exposed to the sun developed a deep red color even though the unexposed surface remained perfectly green.

During recent years the value of good color has become so important that some growers have applied this experience on a commercial scale. Such varieties as McIntosh, Northern Spy, and Baldwin have been placed on a straw mulch on the north or northwest side of a tree and left exposed for 10 days to 2 weeks. Exposure to direct rays of the sun even for an hour is injurious. In some cases cheese cloth shades have been erected from 18 inches to 4 or 5 feet above the apples to avoid sun scald of the fruit. The apples are turned once during the interval, or not, depending upon the degree of coloring wished. This plan has accomplished the desired end at a cost of about 10 cents per bushel. The increased return has been reported at 25 to 50 cents per bushel. It has been considered that delay in storage is a serious matter with most varieties, but growers who report on this practice have not experienced any loss.

Hoffman[31] found that, on December 15, fruit which had been sun-colored on a coloring frame or under the shade of trees had kept as well as fruit stored immediately after picking, all lots being stored at 33° F. To what extent it may assume commercial proportions cannot be predicted at time of writing. When color or spot picking is practiced, the need for such a procedure would be greatly reduced except on such varieties as fail to color before their optimum maturity. With McIntosh spot picking might not be the only solution to coloring. This variety may fall before they color, so that it is necessary in such cases to pick before they drop and then color them.

Spray Residue Removal

The chief means of control of codling moth and other insects injurious to deciduous fruits is arsenate of lead. But at time of harvest fruits frequently hold a residue of spray materials, a portion of which is arsenic and lead, which Federal rulings require shall be reduced to a certain maximum for interstate shipment. That the amounts consumed in using fruits are probably insufficient to cause injury cannot be discussed here, but rather the practical situation as the Federal rulings affect the orchardist.

The provisions of the Federal Food and Drug Act of 1906 established a tolerance of 0.01 grain of arsenic, in the form of arsenic trioxide, per pound of food stuff. This limit became known as the world tolerance. A shipment of pears from the Northwest was seized in Boston in 1916 because of an excess of arsenic residue, which stimulated health authorities elsewhere to examine fruit and vegetable products for "dangerous" spray residues. In 1926 American fruit was seized in England which again focused attention on the problem. By 1927 machines were in wide use in the Northwest for washing fruit. In 1932 an order was issued regarding lead in the residue and a tolerance of 0.025 grain was set up.[26] At the present time (1940) the tolerances stand as follows: 0.025 grain arsenic as arsenic trioxide, 0.02 grain fluorine, and 0.05 grain lead per pound of fruit.

As a result of this requirement to reduce or remove the spray residue of fruit to the tolerance established by the government, a number of investigations were made to learn the best method of accomplishing this and also the effects of such treatments on the fruit itself.

In the first place it may be said that several factors determine whether or not apples will carry amounts of residue exceeding the tolerance at harvest time. Among these are: (a) number of sprays applied; (b) date of last spray; (c) presence of oil in the spray; (d) summer temperatures (which affect wax production); (e) amount of rain.

At first brush or wiper types of machines were used, and still are used for certain purposes, but they did not reduce the load of lead and arsenic to a sufficiently low level when heavy spraying for codling moth was necessary. This led to the use of washing machines of various types, particularly the flotation and the brush washers.

Fortunately, it is possible to remove the load of residue to or below the tolerance by suitable equipment and particularly if washed at harvest time. For instance, it was found that under Eastern conditions washing apples once in an under-brush flood-type washer using either 1 or 1½ per cent solution of hydrochloric acid almost invariably reduced the lead residue well within the present Federal tolerances, even from lots of apples which had received 7 cover sprays with arsenate of lead.[20] (Fig. 71.) A 1 per cent solution is prepared by adding about 3 gallons of commercial hydrochloric acid to 100 gallons of water. The tank should be about half full of water before adding the acid and should be kept well agitated, since the acid settles to the bottom. Exposing apples to acid solutions of 1 to 1.5 per cent concentration longer than 5 minutes is likely to result in injury. It is quite necessary to have an abundance of rinse water (3 gallons per bushel of fruit) if soluble-arsenic burning and contamination by mold spores is to be avoided.[27, 48, 49]

By heating the solution to 75° to 100° F. the residue removal is facilitated, but care must be exercised in raising the temperature above this point and in the use of acid-wetting solutions at high temperatures.

Wetting agents which have been used are Grasselli W. A. No. 2, Vatsol, Lethalate, and Nekal B.

Quite aside from the injury that may occur from the solutions used in removing the residue, there is the important matter of mechanical injuries in handling the fruit, passing it through the machine, and stem punctures that may be increased by the operation. McIntosh apples were injured and thus developed more decay in storage, Kieffer pears developed blackened areas on the skin within a day or two after washing, and other injuries are reported.[21, 32, 46] Nevertheless, many growers who were forced to wash their fruit found that it added so much to its appearance that they preferred to continue this operation even though the residue situation did not require the washing.

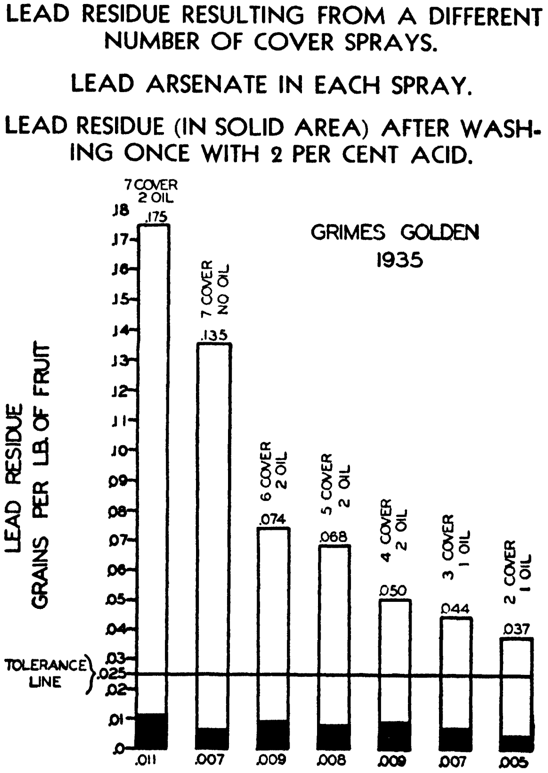


FIG. 71. Results of washing apples to remove spray residue.

Peaches cannot be treated with HCl without severe acid injury by present methods, and therefore dry-wiping machines are used.

Sweet cherries may be washed with dilute solutions of HCl or acetic acid and they should be immediately rinsed with fresh water. They may also be washed in dipping tanks by placing the fruit in small slatted crates. It has been shown that residues above the tolerance are likely to obtain with both sweet and sour cherries where arsenicals are used at any time after the shuck-fall spray, and hence in the future may require washing for fresh fruit consumption.[28]

Grapes may be successfully handled, however, with dilute solutions (0.5 to 1.0 per cent) of HCl. Where grapes are handled at the juice plant only slight modifications of the practice with other fruits is necessary. Grapes may even be washed and shipped wet provided they are carefully handled and are packed in baskets of 12 quart size or less.[37]

Several factors are operative in the successful removal of residues. These include: (a) the type of solvent used; (b) concentration of solvent; (c) agitation of solution during washing; (d) amount of residue present; (e) presence of material other than lead and arsenic (lime sulfur and oil sprays make removal more difficult); (f) amount of wax on fruits; (g) temperature of wash.

Fruit Packages

The package question can never be considered as settled; new types and demands appear and different regions have their preferences. Nevertheless there has been a marked change from a quarter to a third of a century ago when the all but universal package in the Eastern areas was the barrel for apples and pears. The barrel gave way to smaller packages which were easier to handle and which displayed the contents to better advantage.

The next package to appear was the wooden box, which developed with the rise of orcharding in the Northwest. It was and is their characteristic container for apples and pears. Barrels were never used in that section for fruit. Later this package spread to the East, although there were various modifications of it.

The package, however, that was the most direct descendant of the barrel in the East was the round splint bushel basket. It was none too satisfactory, it did not protect the fruit well enough when stacked, the lid often cut the surface apples, and it was largely a jumble pack. Later this was remedied in part by "tub" or other types of baskets which were made of stiffer straight sides and loose bottoms which enabled the grower to put in the face first and pack them upside down like a barrel.

New England continued to experiment with wooden boxes, starting with a flat market produce box which held nearly a peck more than a bushel. It stacked well, was returnable, and displayed the contents to advantage. It was replaced later by one of the inside dimensions 17½ by 7½ by 7$\frac{1}{16}$ inches. This package has dominated that region for 20 years, but has never been popular elsewhere.

Later a Northeastern apple crate appeared which was ideal for shipping such tender varieties as McIntosh without bruising. It originated in the Hudson Valley and was quickly adopted over a wide area, supplanting both the bushel basket and the New England box. The crate ultimately agreed upon had the dimensions of 17 by 14 by 11 inches, inside measurements, and held 1⅛ bushels of apples.[61] In case refrigerator-car loading demands variation from such dimensions, a box 16 by 13⅝ by 12 inches may be used.

This box is used in the export trade and seems to be satisfactory when given a cushion top held down firmly by slats. It was estimated that 85 per cent of the total commercial apple crop of New England was marketed in this package in 1939.

A comparison of cubic contents of different packages can be seen from the following figures:

Standard apple barrel (about 3 bushels)	7,056	cu. in.
Bushel (U. S. Bureau of Standards)	2,150.42	" "
Winchester bushel (adopted 1836)	2,150.42	" "
Standard Western apple box (10½x11½x18 inches)	2,173.50	" "
Round-stave basket	2,150.42	" "
Slat crate (lug package)	2,700.00	" "
Boston bushel box	2,592.00	" "
New Boston box	2,163.00	" "
Northeastern apple crate	2,618.00	" "

Peaches are usually handled in bushel or half-bushel baskets in the East although in some sections the 6-basket crate is used. This contains 6 4-quart till baskets placed in 2 tiers with a dividing tray. Other sizes of hampers and crates are also used, as the ⅝ bushel hamper of New Jersey. In the West a box is used for peaches which is 11½ by 18 inches and varies in depth from 2 to 6 inches.

Berries are sold in boxes and these in turn are packed in crates, holding 24 pints, 24 quarts, or 32 quarts. Special types of boxes, cups, and other containers are also used in certain markets. The Hallock type of berry box is widely used and is recognized by having a raised bottom which at one time was an objection. It has however become a favorite in Minnesota, Michigan, Oregon, Washington, and other states. There is a trend toward covering the boxes with cellophane or other material to make them more attractive and afford better protection.

Citrus fruits are usually packed in boxes. The California box holds 1.47 and the Florida box 1.6 bushels. Oranges and grapefruits also appear on the market in mesh bags, baskets, or are shipped in bulk by car or truck.

Plums, prunes, and apricots are packed in Climax baskets, bushel and half-bushel baskets, or in the West in a box known as the "suit case." The latter commonly has the dimensions of 3¼ by 11½ by 18 inches inside, but other sizes are used.

The American type of grape is commonly put in Climax baskets, holding 2, 4, or 12 quarts. These sizes, with their capacities and measurements were established by law by the enactment of the United States Standard Container Act. The *vinifera* grape crop of California is shipped in lug boxes or in kegs or drums. If the latter is used sawdust or cork is used as a packing material.

Smaller types of packages and corrugated boxes are used holding 40 pounds net or less of apples. The paper boxes or cartons are provided with dividers so that each apple is surrounded entirely by paperboard, after the fashion of an egg crate.

FRUIT STORAGE

Storage developments over the past half century represent a most valuable contribution of scientific and mechanical skill in making perishable products available over a relatively long period of time. Storage usually refers to cool or cold storage of products and may be defined as the means by which perishable products are maintained at a temperature sufficiently low to arrest disease and the natural physiological and chemical processes of ultimate maturity and decay, yet not sufficiently low to injure the tissue or quality of the materials stored. Tressler and Evers define refrigeration as "*a process of removing heat from a confined space* for the purpose of reducing and maintaining the temperature of the enclosed space below that of the external atmosphere." [60] Here also the student will find a discussion of the principles of refrigeration.

The extent to which civilization has come to depend on cold storage is expressed by Birdseye as follows: "In the past thirty years, the use of mechanical refrigeration has grown so tremendously that no urban population in the United States could survive for more than thirty days or so without cold storage foods of one sort or another. New York, I believe, could not live for more than ten days to two weeks at the outside without cold storage foods." [8]

The Common or Air-cooled Storage

This term arises from the fact that the natural temperatures of the outside atmosphere are used to cool fruit in a storage room. The cooling is accomplished by the intake and circulation of air that is colder than the air within the building, thus neither ice nor mechanical refrigeration is used for the purpose. This system is only adapted where the naturally occurring temperatures are low enough to greatly check ripening processes; otherwise the purpose of the storage cannot be accomplished. Its cheapness and the lack of adequate cold storage near points of production led to a wide usage of the method throughout the Northern states and Canada.

Proper construction of the building is important, but efficient management as well is essential to the success of this type of storage. This means that the building must be closed during warm periods and opened during cool nights so as to pass the maximum of cold air through the building. Carelessness in opening the building either to remove fruit, or for other purposes, when the temperature is high, is a common fault.

That the common or air-cooled storage evolved from the cave, the cellar, or the barn, is quite evident. It was long realized that the earth maintains a more uniform temperature than air, ranging from 50° to 60° F. Aboveground storages are insulated sufficiently to maintain a uniform temperature. The heat given off from the earthen floor about balances that lost through the walls and ceiling, and, if the room is well constructed, a uniform temperature of around 32° F. can be held once the room is cooled down to that point. Very careful management is necessary to do this, however.

Type of building.[16] Any building, when properly insulated and provided with sufficient ventilation through openings or doors, may serve as an air-cooled storage for apples. Farm buildings, abandoned school houses and churches, and other structures have frequently been successfully remodeled for this purpose. Special reinforcement may be necessary in the load-bearing floors. They may be constructed entirely below ground with more or less of their wall and roof surfaces exposed, or entirely aboveground. Likewise there is a wide choice of material for construction. Whatever building is used, every precaution should be taken to eliminate rats. The air inlets and doors should be well screened with ¼ inch hardware cloth and the same protection should be put under the fruit. The screen may be placed directly on the earth floor or it may be laid in the sleepers and under the slats. Care should be taken that there is a good joint between the screen and foundation.

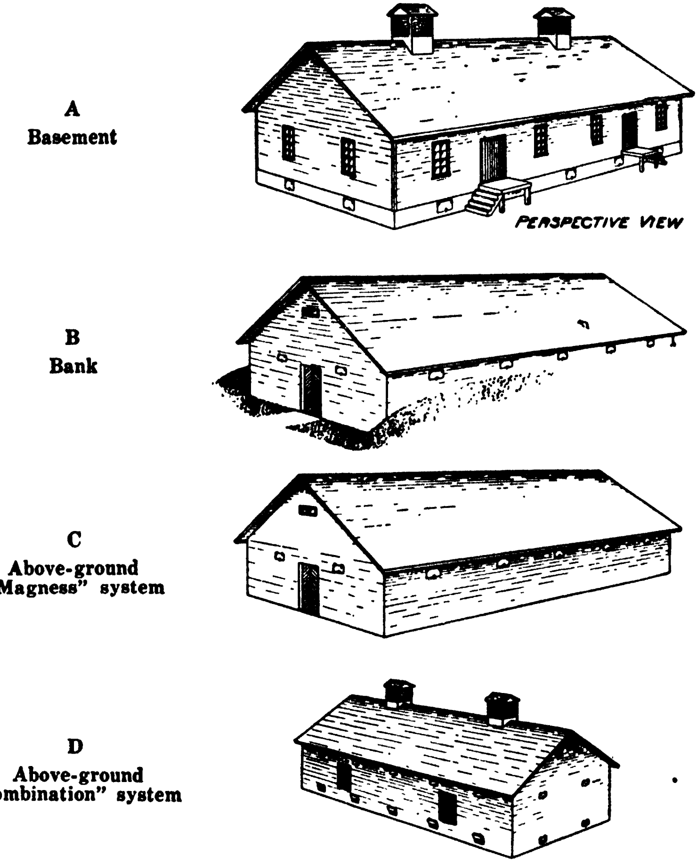
While there is no substitute for cold storage, the common storage may be vastly superior to facilities formerly available. Nevertheless, the trend is toward the cold storage on the farm because of the demand to deliver the fruit to the consumer when it is not only of prime quality, but also of prime appearance.

Systems of ventilation.[15, 16, 35, 42, 43] There are several systems of ventilation and combinations of these employed in the construction of common storages, *viz:*

1. Natural gravity ventilation
   (a) Cope system
   (b) Magness system
   (c) Combination of (a) and (b)
2. Forced ventilation
   (a) Power fans
   (b) Cowl-induced
   (c) Wind pressure

The Cope System. Nathan Cope of New Waterford, Columbiana County, Ohio, procured in 1869 a United States patent for his invention, "Improvement in Fruit-Houses." His system utilized the principle of providing for the entrance of cold outside air into a storage house through openings distributed around its walls at the floor level; this air by virtue of its greater weight replaced warmer air which was thus forced out through a flue in the ceiling.

The Magness system. Many of the older storages in America were built as basements to apple-packing houses. The floor of the packing house was usually constructed not more than 2 or 3 feet above the ground level; this provided sufficient space for ventilation openings around the ground line or just below the ceiling of the basement room. (Fig. 72A.) Magness, by controlled experiments, established the essential principles in cooling fruit in an air-cooled room. He found that, when the cold air was delivered at the floor of the storage (Cope System), the fruit in the lower layers cooled far more rapidly than the fruit in the top of the stacks. A temperature difference between the top and bottom layers always existed even when the temperature of the bottom layers was at a safe minimum. With air entering only at the room ceiling, the fruit cooled at the same rate throughout the storage and the top layers cooled more thoroughly than when the Cope System was employed.



(From U. S. Dept. Agr. Mimeograph, Washington, D.C.)

FIG. 72. Four types of common or air-cooled storage houses. Combining a grading and packing room with an underground or basement (A) is economical of material and space. Note the absence of outlet vent-flues in the earth-banked (B) and aboveground (C) which is characteristic of the "Magness" type. The storage banked with earth would prove the least satisfactory of the four types. A combination of the Cope and Magness systems of ventilation (D) is to be recommended where the greatest satisfaction, irrespective of cost, is desired.

He concluded that air inlets on the same level with or above the top of the fruit stacks are absolutely essential to the equal cooling of the fruit. (Fig. 72C.)

The theory of the Magness System is based on the fact that cold air, being heavy, will find its way through ventilator openings and drop to the floor of the storage, forcing the lighter air out through the same openings. In case the wind is blowing, faster cooling will take place as the cold air blows in on one side of the room, across the top of the fruit, and out the other side.

It is possible to combine the Cope and Magness systems. (Fig. 72D.) Such a type of construction gives the maximum of rapid cooling under all storage conditions, for, when the outside air is cold and immobile, it passes in through the bottom openings, up through the fruit, and out through the top openings in the walls and through the ceiling flues. Whenever the wind is blowing, the cold air enters through the side openings at the top and bottom, passes over and through the fruit containers, and out at the other side. Such a system is somewhat more expensive to construct than other types but will prove more satisfactory in operation during the entire season.[16]

Use of ice as a refrigerant. Various experiences are reported from the use of ice in air-cooled storages. The fact that the temperature in these rooms is likely to be all too high during the first few weeks of storing has led some growers to install ice bunkers. This practice was not uncommon a third of a century ago. It is not unusual for the temperature in the storage rooms to be higher than outside after they are filled with fruit. With such varieties as Jonathan, McIntosh, Delicious, and Grimes Golden, ripening proceeds at a destructive rate in some seasons.

Baker and Mayer [6] have shown some excellent results from the use of ice in air-cooled storages. Circulating the air over ice reduced the storage temperatures 10 to 16 degrees below the temperature of an air-cooled room used for comparison. Circulating the air through cracked ice and salt reduced the temperatures 18 to 20 degrees in the insulated as compared to the uninsulated air-cooled room.

While inferior to mechanical refrigeration it prolonged the sales period of Grimes Golden and Jonathan past the holiday season. The seasonal cost of icing and operating the iced room varied from 16 to 26.6 cents per bushel of apples with an average of 20.8 cents for six years.

The experiments of the Cornell Station, on the other hand, would hardly seem to justify the practice,[15] and the experience of most growers would tend to confirm their results.

Mechanical refrigeration. The second type of storage is that of mechanical refrigeration or "cold storage." This industry was formerly in the hands of commercial concerns entirely, for the expense of construction seemed to make it prohibitive on the farm. This situation has changed markedly during the past ten years, and many such units have appeared in the fruit-producing areas. The change has been brought about because of increased selling at the farm, cost of renting storage space, and the increasing need of lowering the cost of production and disposal of the crop. Ballou [7] has shown that storage and transportation charges make up approximately 30 per cent of the cost of growing a bushel of apples and preparing the apples for market.

One of the deciding factors on storage construction is the size of crop which is produced. It has generally been agreed that nothing less than a 10,000-bushel crop would justify a cold storage on the farm and a 30,000- or a 50,000-bushel storage would cost less per bushel than a smaller one, although a number of less capacity have been built and the growers appear satisfied with the results.

A recent survey in New York, Massachusetts, Connecticut, and Ontario showed that five reasons are commonly given by growers for owning their own storage: (1) The cost is less than that of commercial storage because labor and other overhead costs are less on the farm, and also because, by the use of air diffusers, relatively high refrigeration temperatures can be used; (2) the grower is better able to choose his market; (3) the necessity of grading and packing at picking time is eliminated; (4) there is opportunity for precooling fruit; and (5) the grower has personal supervision over his own fruit. Thus he can sell when it seems to be going down in firmness, if scald or other storage diseases develop, and he can watch for shrivelling. In this survey, out of 85 storages of apples on the farm, 55 were refrigerated and 63 per cent of the common storage owners reported that they were interested in changing to refrigeration. The same change occurred in the Pacific Northwest where the growers' organizations came to realize the importance of placing each variety on the market when it was at its best. These facts are cited as evidence of the rapid change from common to cold storage on the farm.

Already the cold storage industry has been affected by this innovation and the centralized cold storage plant does not hold the place in perishable fruits that it did a few years ago. The trend is toward cold-storage space at the points of production with an increasing amount of f.o.b. sales.

A note of caution along this line cannot be amiss, however. To construct a cold storage (or to assume heavy overhead expenses in any other way) on a fruit farm before the enterprise has demonstrated its ability to carry it, must be regarded as similar to any other gamble. Many growers have met with disaster by overcapitalization, and a considerable part of the tragedies that have occurred in American orcharding is due to this error.

Cost of a refrigeration system. The total construction costs for cold storages, complete with refrigeration equipment, will range from about a dollar per bushel for smaller ones down to 60 cents or even less per bushel for those of larger capacity. The operating expenses per year for a well-managed storage of 5,000 bushels capacity are estimated at 6 cents per bushel and fixed charges at 10.3 cents, or a total cost of 16.3 cents per bushel. For larger storage the total cost would be from 10 to 15 cents. It is frequently possible to refrigerate 10,000 nearly as cheaply as 6,000 bushels.

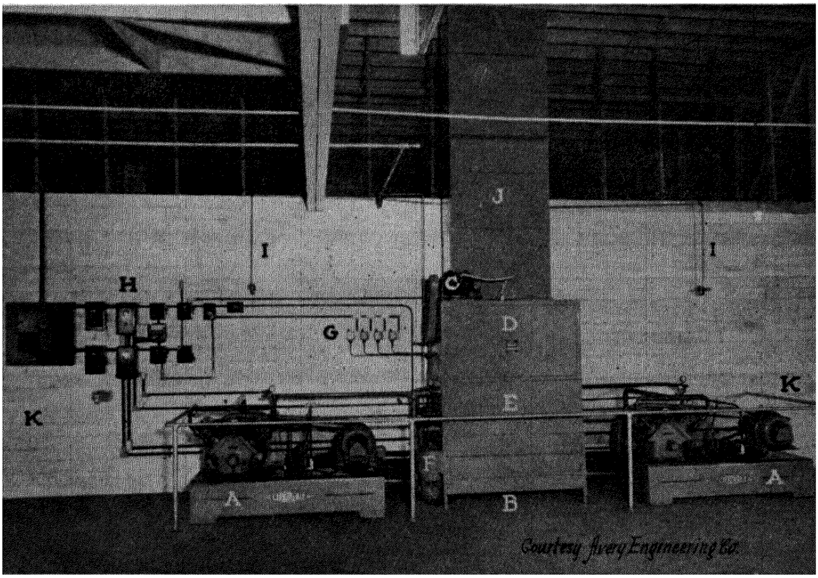
Forced-air storage. The usual type of mechanical refrigeration has been to install bare pipe coils (either direct expansion or brine) along the walls or suspended from the ceiling. The next attempt at improvement of this system was to provide fans directed toward the pipes. This increased the air circulation over the pipes and thus hastened the natural heat exchange from the fruit to the cooling coils. More recently special type coils have been devised whereby the heat exchange surface was increased through the use of fins, and this type is known as "flash" coils.

An adaptation of the flash coil is the "blower" or forced-air circulating unit in which the cooling pipes have been concentrated into small spaces with blower fans attached to aid in the rapid circulation of air and its distribution throughout the fruit packages. There may be one large unit installed in a cabinet which is located either inside or outside of the insulated room, or there may be several small coil units suspended from the ceiling or walls. Any refrigerant and compressor may be employed and there are different styles of blower equipment. (Fig. 73.)

The latest designs in refrigeration take the form of blower or forced-air circulating units containing finned coils of the dry or wet type. The wet coil is continually bathed with a brine solution which prevents frosting of the coil thus allowing lower storage temperatures to be maintained. It is not satisfactory to operate a dry coil cooler at temperatures lower than 33° to 34° F.

Occasionally an air-washer system may be employed which cools the storage air continually by contact with brine in a plenum chamber.

A comparison of the coil and blower systems was made by the New Hampshire Station. It reports a greater temperature variation in the coil type. For instance, when the center of the room was regulated to 30° to 32° F. the fruit near the coils or floor was likely to freeze. The rate of cooling of the fruit was much greater in the blower system, 250 hours being required to cool 250 boxes of apples in the coil room as compared to 48 hours in the blower room. No differences were found in pressure, acidity, or ground color in the fruit stored in the two types of storages. Brown core and breakdown were more severe in the coil room, but there was a greater loss of weight in the blower type, especially from the fruit in the direct path of the air draft.[51] This latter was not great enough to be significant, however.



Courtesy Avery Engineering Co.

FIG. 73. Modern mechanical refrigeration equipment.

Precooling fruit for shipment.[2] It has been known for some years that fruit will carry better and keep longer if it is cooled immediately after it is picked from the tree and before it goes into cold storage or refrigeration cars. This is particularly true of citrus and such soft kinds as peaches and berries.[52] Lack of facilities and the expense involved have been the chief obstacles to its wider use.

In shipping fruit for long distances by water it is of the greatest importance to precool it without taxing the refrigeration unit in the hold of the ship. The very fact that the temperature of the fruit is brought down quickly to near the carrying point does much to insure better quality and less molds and other diseases.

Fruit may either be precooled before it is loaded on cars or afterward. In the former case the fruit is placed in a cold storage warehouse under mechanical refrigeration and in the latter case it may be accomplished by mechanical refrigeration or by ice. When the cars are assembled for precooling, cold air from a precooling plant or cold storage is circulated through them in such a way as to cool the top of the car as well as the lower regions to the minimum temperature. By the use of fans the air is circulated much more rapidly and uniformly than occurs from the natural circulation. Combinations of these two types are also in use.

Partial precooling may be accomplished by placing fruit in a shed over night before packing and loading. There are regions where as much as 50 degrees difference between day and night temperatures obtain during the harvesting season.[47]

The temperature of a fruit (or any substance) is known as its thermal state. Since its heat or kinetic energy cannot be perceived directly it is measured by its effects. The arbitrary unit of measurement is the British thermal unit (B.t.u.) which represents the amount of heat required to raise the temperature of 1 pound of water 1° F. when the water is at its maximum density (at 40° F.). In commercial storage or in precooling practice, the heat in fresh fruits is usually computed from the freezing point of pure water, or 32° F. Thus by substituting 32° F. as a base instead of absolute zero, one ascertains the heat at 80°, for example, by multiplying the weight, in pounds, by the specific heat, and the result by the difference between the existing temperature and the base temperature to which the fruit is to be cooled. Thus this computation, 2,000 x 0.9 x 48 = 86,400 B.t.u., approximates the heat above 32 degrees which a ton of fruit may contain at a given moment.[2]

In addition to the field heat which it contains, fruit is constantly respiring and one of the products of respiration is the release of energy in the form of heat. This introduces a factor in storage calculations which engineers did not at first fully comprehend. This heat of respiration is commonly computed in terms of rate of carbon dioxide evolved (usually expressed in milligrams per kilogram of fruit per hour, or the mg. of CO_2 per Kg.-hr.) and the heat of combustion of the sugars consumed in respiration.

Hawkins[30] has compiled the respiration rates obtained by numerous investigations from CO_2 output and has computed the heat of respiration in B.t.u. According to these data, a ton of peaches held for 24 hours at 32° F. will liberate 1,540 B.t.u., whereas if held at a temperature of 80 degrees they will liberate 15,400 B.t.u. The heat of respiration from this fruit at 80 degrees thus amounts in one day to nearly 18 per cent of the 86,400 B.t.u. they originally contained above 32 degrees. Aside from temperature differences, kinds of fruit vary widely in their respiration rate, the quickest-ripening, most perishable products having the highest rate, and citrus fruits the lowest.

Refrigeration necessary for precooling. Refrigeration is measured in terms of the standard ton, or the quality of heat (expressed in B.t.u.) required to melt a ton of pure ice at 32° F. into water at 32° F. Mechanical refrigeration capacity is expressed in tons per day, or a rate of heat removal equal to 288,000 B.t.u. per day, or 12,000 B.t.u. per hour.

To calculate the amount of refrigeration (or of ice) necessary to cool a 26,000 pound load of fruit from 80° to 40° F. the number of B.t.u. to be removed is divided by the number of B.t.u. absorbed by each pound or by each ton of ice, as follows: 26,000 x 40 x 0.9* = 936,000 B.t.u.

Since, in melting, each pound of ice absorbs 144 B.t.u., or each ton 288,000 B.t.u., the ice required would be $\frac{936,000}{144} = 6,500$ pounds, or the equivalent of 3.25 tons of refrigeration.

To cool a 36,000 pound load from 80° to 40° F. a total of 9,000 pounds, or 4.5 tons, would be required, while to cool the same load to 32° would necessitate 5.4 tons of refrigeration. These calculations show only the amount of ice or refrigeration necessary to cool the fruit exclusive of the heat of respiration.

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* For most fruits and vegetables the value of 0.9 B.t.u. per degree Fahrenheit is used. The specific heat for Bartlett pears calculated from data by Rose, *et al.* would be 0.872 B.t.u..[53]

Under most favorable cooling conditions, small fruits in open packages require several hours of precooling, while tightly packed fruit in refrigerator cars or in storage rooms may require several days.

In addition to the items considered there are other ones which enter into the problem. The heat of respiration, the packages and packing material, and the heat generated by motors and fans. Thus the entire problem was calculated as follows for cooling a theoretical car of fruit from 80° to 40° F. over a period of 24 hours:

	Pounds of Ice
Fruit: 26,000 pounds cooled from 80° to 40° F.	6,500
Fruit: Heat of respiration during cooling	770
Boxes, fruit wraps, box pads, car strips, bracing, etc.	375
Leakage of refrigeration around openings and through walls, roof, and floor of car	585
Heat generated by two ½ h.p. motors and fans	650
Total refrigeration, exclusive of initial cooling of car	8,880

Modified atmosphere storage. Trials have been made for some years on the effect of artificial atmospheres in the storage and transit of fruits. As early as 1821 Berard was presented with a medal by the French Academy of Science for his paper on the storage of fruit in atmospheres devoid of oxygen, but it is only within the past few years that interest in the subject has developed from a commercial standpoint.[18] Its application has proceeded farther in England than America, although experiments in disease control and in transit of fruits in this country are fairly extensive.[1, 10, 11, 25, 33]

Smock [56] has described this type of storage and the results procured by it. Such work changes rapidly and the student should consult current literature for most recent reports. He points out that respiration is diminished in intensity not only by lowering the temperature (as in cold storage) but also by reducing the amount of oxygen or allowing carbon dioxide to accumulate. In "gas" storage of fruit, control of the composition of the atmosphere is the predominant feature. It will be recalled that oxygen comprises approximately 20 per cent of the volume of air in a cold storage room.

"By use of gas-tight structures and controlled ventilation, the desired proportions of carbon dioxide and oxygen can be easily attained in most cases. For example, suppose an operator desires an atmosphere containing 10 per cent carbon dioxide and 11 per cent oxygen. The respiring fruit in a gas-tight, metal-lined, storage chamber produces an accumulation of carbon dioxide which finally reaches the desired 10 per cent value. By difference from the normal air figure of 21 per cent oxygen, the oxygen value will now be 11 per cent, since during the production of carbon dioxide almost an equal volume of oxygen has been consumed. In such a system, frequent determinations of the carbon dioxide are made on a Katharometer outside the chamber and if the carbon dioxide exceeds 10 per cent, a port in the door is opened until the proper percentage has been attained."[54]

No satisfactory figures are available, as yet, on the cost of modified atmosphere storage in the United States. It is figured in England that, excluding the cost of oiled paper to prevent scald, the cost is about the same for gas as for cold storage, since refrigeration and insulation requirements are usually less with gas storage. This would probably not hold in the United States since our cold winters would necessitate use of as much insulation as for cold storage. Kidd and West[33] have estimated the per bushel cost per season at 25 cents in a storage holding about 2,000 bushels.

Allen and Smock[4] conducted experiments in California on the storage of apples, pears, plums, and peaches in atmospheres containing various percentages of carbon dioxide, experiments which are typical of similar well-conducted tests. This work showed that Yellow Newtown apples held in CO_2 concentration of 10 per cent at a temperature of 45° F. were as green and firm as in air temperatures of 32° and 36°. Similar results were obtained with Yellow Bellflower apples and Bartlett and Beurré Hardy pears.

The results with plums and peaches indicated that the effects in retarding coloring and softening were marked when they were held at 45° F. for 10 days, corresponding to the period of overland shipment from California. The treatments of CO_2 concentrations of 20 to 80 per cent for 6 days were successful.

Later work by Smock and Van Doren[56] has shown the possibilities of gas storage with other varieties subject to low-temperature troubles. Northwestern Greening after 30 weeks in 5 per cent carbon dioxide and 2.5 per cent oxygen at 40° F. was still as green as when first stored and had only a slight amount of brown core (mealy breakdown). All fruits were marketable. Comparable fruit stored in normal air at 40° F. for the same period was completely broken down and worthless because of brown core, while fruit stored in 36° air was wholly unmarketable after 30 weeks because of softening, yellowing, and 100 per cent brown core.

McIntosh which is the leading apple variety in New York and New England, cannot be stored at 32° F. with any assurance that it will remain in prime eating quality after February first. The Cornell studies indicate that by using suitable atmospheres there may be a real future for long keeping of this variety. McIntosh stored in 5 per cent carbon dioxide and 2.5 per cent oxygen retained its full flavor and crispness for 30 weeks at 40° F. and was free of brown core. When stored in 36° F. air this variety developed considerable brown core, and was lacking in quality after 30 weeks.

Kidd and West call attention to the importance of proper maturity of the fruit in the successful management of the gas storage. This is because the onset of the climacteric* phase is suppressed or postponed in apples that are held from the time of gathering in an atmosphere containing 10 per cent of carbon dioxide. Hence the beneficial effect of the gas storage will largely be lost if the fruit has reached its climacteric before it is stored. The interval between the picking of the fruit and the sealing of the gas store should not exceed 5 days.[34]

Preservation of fruits by freezing. The freezing of fruits and vegetables as a means of holding them in ready-to-serve packages for the retail trade instead of using heat and canning them, has rapidly assumed large proportions. To what extent it will replace cold storage and canning as a method of preservation cannot be predicted, but it is certain to be an important factor. Such fruits as the apple, peach, strawberry, blueberry, raspberry, and blackberry are now available in quantity. Research will doubtless add much to the technique of the process. Already there is extensive literature on the subject.[13, 14]

Fruits for freezing should be well colored and ripened, yet firm. The fruit should be washed thoroughly but so handled as to prevent crushing. The containers used for soft fruits are waxed fibreboard, lacquered metal pails, or hardwood barrels. Pails of 20 to 30 pounds capacity are suitable for restaurant or institutional use and barrels are generally used to freeze fruit for use in jam making.[5, 17]

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* The climacteric is the normal peak in the respiration rate. Even at the same temperature apples do not respire at the same continuous rate. After harvest they reach a peak and then the rate declines. The word really means "change of life."

Various temperatures have been used for freezing but most of it is done in the range of minus 20° to 0° F. and then stored in air temperatures of 0° to 10° F.

In their preparation fruits may be packed either wet or dry. In the former method they are packed in a watertight container, covered with a prepared sugar syrup or brine, closed and frozen. In the latter method rectangular paperboard containers are used. They are lined with moisture-proof material and the filled package wrapped with a moisture-proof material and preferably heat sealed.[60]

The variety is an important factor in frozen fruits, some processing much better than others. The strawberries most commonly used are Marshall in the Northwest and Blakemore and Senator Dunlap in the Middle West and East. The leading ones in the South are Klondike and Missionary. The Premier proved satisfactory in Ontario, whereas the rich-flavored, deep-colored sorts were found to develop a "preserved" flavor. Most of the raspberry varieties have proved satisfactory, although the lighter-colored reds are more attractive, Cuthbert being the best. The large black varieties of cherries make a superior product to the light-colored ones of the Royal Ann type. Few peaches have as yet been suitable as they oxidize rapidly and turn brown after freezing. J. H. Hale and Elberta (from the West) have comprised the bulk of the commercial pack of frozen peaches to date. Both of these are yellow, freestone sorts. The time of picking proved to be a very important factor to avoid darkening or oxidation. Sunbeam and Eclipse were particularly favorable in experimental trials. Blueberries make a fine product either with or without sugar.[12]

Probably the one big problem at present is that of providing refrigeration in the various steps of distribution. The fruits must be kept at low temperatures in storage, and the distributor must provide refrigeration in transit to the retail merchant. In order for the retailer to merchandize this type of product without loss he must make an investment for a cabinet that will hold adequately low temperatures, or else rent one. The consumer must use the products in a relatively short time, approximately twenty-four hours after defrosting. It is likely that manufacturers of household electric refrigerators will incorporate sufficient space in the freezing compartment to properly hold a reasonable quantity of this type of perishable food.

Methods of processing frozen fruits. So rapidly has this industry developed that the methods change and what is standard today may be obsolete tomorrow. Tressler states that the methods employed are really quite simple. "Fruits are prepared as for the table and then either mixed with sugar and packaged, or packaged and then covered with a heavy sugar syrup. After closing, the packages are either placed in a sharp freezer or in a quick freezing machine. . . .

"Fruits, with the exception of apples, cannot be scalded without the development of a cooked taste. Since the principal advantage of freezing preservation is the fresh flavor and color of the frozen product, other methods of preventing objectionable enzyme actions are used. The addition of sugar or sugar syrup is the best method of retarding oxidation and other objectionable changes which may occur during cold storage." [58]

What has been termed "cold pack" or "frozen pack" has been used for a number of years (at least since 1905) and consists in packing hulled and washed small fruits with sugar in barrels or smaller containers at temperatures of 0° to 10° F. above zero. The product is usually used in making ice cream and pastries. Strawberries and red raspberries are extensively handled in this way in the Pacific Northwest. This has long been practiced in the Puyallup section of Washington. Cherries are often cold packed in Michigan and New York, and cranberries are frozen in bulk in Massachusetts.

In "quick freezing," fruits are placed in small containers and the heat extracted from the top and bottom of the package simultaneously, thus permitting very rapid freezing. This method is extensively used with whole and sliced strawberries, raspberries, blueberries, cherries, peaches, boysenberries, and youngberries. An extensive development has taken place for strawberries at Ponchatoula, Louisiana, where the ammonia gas system is used.

The advantages of quick freezing, as listed by Tressler [58] are that the ice crystals formed in the product are smaller and hence are less destructive to the cell structure. Since the freezing period is much shorter, less time is allowed for the diffusion of salts and the separation of water to form ice. The product is quickly cooled below the temperature at which bacterial mold and yeast growth occur, thus preventing decomposition during freezing.

Cold storage lockers.[59] A distinct innovation in the freezing and holding of fruits is the individual cold storage locker. Mann [41] traces the history of this movement from 1903 to the time of writing.

From a modest beginning at Chico, California, the idea spread slowly until 1935 when it had a very rapid development, not only in the West but throughout the Middle West and South. By 1939 it was estimated that some 2,500 plants were devoted to food lockers in the United States and that others were being established at the rate of about 50 per month.

Individual cold storage lockers are of two general types consisting of either limited or complete service. They may be incorporated within a commercial cold storage plant, an ice manufacturing plant, or they may be built expressly for the purpose. An establishment having limited service usually has one large room containing the individual lockers where fruit is both frozen and stored. Facilities for processing and packaging are not provided. Plants having a complete service usually maintain a chilling room (32° to 36° F.); a cutting or processing room; a sharp freezer (10° to 12° F. below zero) where actual freezing is done; and the storage or locker room where fruits are placed under individual accounts. The temperature in the holding room ranges from 10° to 12° F. above zero, sometimes lower.

The great advantage of cold storage lockers is the elimination of the regular in-and-out handling fee charged by cold storage houses in their regular business which is often prohibitive for the individual. The usual charge for locker service is $1.00 per month, or $10.00 per year. A nominal fee may be charged if fruits are processed and packed in the locker plant prior to freezing.

In freezing fruits it is generally recommended that they be packed in a heavy syrup, whether in airtight or nonairtight containers. When packed in the containers, room should be left for the expansion caused by freezing.[59] An excellent product is secured by mixing sugar with the fruit and allowing the juice of the fruit to dissolve the sugar. This procedure gives a high quality product but the shape of berries is sacrificed.

This development has stimulated widespread interest in frozen foods and the trend is toward its further spread.

One of the most recent innovations is a system where sets of four lockers are arranged as one vertical unit. Units are placed below an insulated floor of a room with normal temperature. The subfloor room where the lockers are located is held at the proper low temperature. When a patron wishes to use a locker, the unit desired is raised by an electric winch through a trap door. After use, the unit is lowered back into the cold room and the door, which forms part of the floor, is shut. This arrangement means that patrons do not have to enter cold rooms to use their lockers.

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WINTER INJURY

Most of the tree fruits and part of the small fruits and grapes are either exotics or have arisen as a result of crosses of species or varieties which are not indigenous to the United States. Many of the fruits came originally from the Levant or other regions whose climates are less harsh and variable than those of the fruit regions of America. As a result the fruit grower is concerned with temperatures in autumn, winter, or spring which result in injury or killing of tissues or entire plants. Such experiences are all too common and the horticulturist has sought hardier sorts as well as means of preventing injury.

There is a vast literature dealing with the history of winter injury, particularly in reports of horticultural societies, in experiment station bulletins, and scientific publications. In each generation there are those who contend that "the climate has changed," but the oldest weather records and other means of obtaining such information fail to substantiate this view. That the vagaries of the weather are many and that no rhythm obtains as to frequency of exceedingly cold or warm winters (or other weather phenomena), is well established.

Exceedingly cold winters or what have been called "test winters" are recorded in the following years at various places in the United States, although a very severe winter in one region may not be duplicated in others, and records of early years are not available from all states; 1779–80, 1796–97, 1817–18, 1834–35, 1855–56, 1863–64, 1872–73, 1874–75, 1878–79, 1880–81, 1883–84, 1884–85, 1898–99, 1903–04, 1906–07, 1911–12, 1917–18, 1933–34, and 1935–36.[25] These dates apply largely to the North where during the period of over 160 years there have occurred at least 19 recorded winters, or approximately one year in 9, in which abnormally low temperatures have been attained. In the South the winters of greatest injury are often those in which warm periods occur followed by perhaps only moderately cold weather.

How freezing kills. There are several theories, each supported by extensive observations and experiments, as to exactly what happens when a tissue is frozen and also what predisposes a plant to such injury. There is, even yet, no complete agreement among those best qualified to judge as to how freezing kills. It must be understood that a tissue may be frozen and recover, a rather frequent occurrence, or it may be frozen to death. "Frozen to death" is a technical phrase describing plant tissues which have been subjected to a temperature at which death of their cells occurs. Such tissues present a brown, water-soaked appearance shortly after they thaw, and evaporation is much more rapid than from living tissue.

The theories which have been advanced to explain how freezing kills assume that the injury may be due to at least one of the following: a denaturing of proteins which results in a destruction of their natural properties, a shrinkage or breaking of the cell or its wall (mechanical injury), or a coagulation or precipitation of the protoplasm. In this connection Harvey states that "in moderately low temperatures plants frequently escape freezing by undercooling of their saps without ice formation. Many species escape winter-killing in this manner. The low temperature is not harmful in itself. It is the concentration of the sap by withdrawal of water to form ice, thereby increasing the salt concentration and hydrogen-ion concentration, which irreversibly precipitates the plant proteins, changes the permeability and organization of the cell, and causes injury from freezing. A high content of strongly hydrophyllic colloids, such as pectins or gums, makes possible great undercooling. Yet the cacti and such succulents are not the hardiest plants. High sucrose content makes undercooling possible, and sucrose also decreases protein precipitation. Yet sugar beets are not the most hardy plants. A layer of wax over the leaf surface prevents the formation of ice crystals in the cuticle and allows undercooling of leaves." [26] Chandler and Hildreth's work [11] with pollen of Lukens Honey peach, Himalaya blackberry, a variety of Amaryllis, and a variety of yellow snapdragon, indicated that killing of protoplasm at low temperature is not due to the concentration or changing of the sap caused by freezing out of the water, as some have thought, but is due to the direct effect of the ice masses.

Usually ice crystals form in the intercellular spaces from water that is withdrawn from the cells, but ice crystals may also be formed within the cells, if the freezing is very rapid. In either case both mechanical and chemical changes may take place as well as some modification of the colloidal structure of the protoplasm. On the basis of present evidence it can be said that whatever the mechanism of freezing injury, any change which reduces or prevents ice formation will increase the resistance to injury.[40]

From a different standpoint, the causes of killing of winter-injured apple trees has been studied histologically. It was found that the degree of killing was related to, (1) the number of vessels which become occluded, that is, contained "wound gum" which prevented the passage of water and solutes, and (2) the amount of parenchyma cells of the xylem and rays which were killed. Statistical evidence correlated closely the amount of killing with the per cent of occluded vessels and dead parenchyma. If 50 per cent of the vessels were occluded, the branch was not likely to recover, but if only 20 per cent were occluded, recovery was probable. About the same percentages obtained with dead parenchyma cells and killing of the branches.[43]

Three factors are concerned with the amount of injury from freezing, namely, duration of the low temperature, rate of temperature fall, and the rate of thawing.

It has been shown experimentally both with apple roots[36] as well as with aboveground portions[27] that the length of exposure to low temperature has a marked effect upon the amount and severity of the injury, the killing being more or less in direct proportion to the duration of freezing. Obviously, however, when very low temperatures occur, just as severe injury may develop from a few hours' exposure as from many.

The rate of temperature fall also has a pronounced effect upon the results.[11, 27] A very rapid fall will kill at a temperature several degrees higher than when the temperature fall is gradual. Chandler and Hildreth report "Yellow Newtown apple twigs were badly damaged by being moved directly from air at 20° C.* into sodium chloride solution at −12° C. and left 11 minutes. There was no

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* To convert Centigrade and Fahrenheit temperatures:

$$\frac{\text{Degrees F.} - 32}{1.8} = \text{Degrees Centigrade (C.)}$$

$$\text{Degrees C.} \times 1.8 + 32 = \text{Degrees Fahrenheit (F.)}$$

damage to other twigs left 25 hours in the same solution in a warm room or to others cooled slowly in air to −17° C. and left 40 hours." [11]

The rate of thawing may or may not be a factor in the amount of killing. In observations after spring frosts, it may be plainly seen that shaded or protected leaves or fruits are damaged less than those which are exposed to bright sunlight soon after the low-temperature period. If, however, the temperature is sufficiently low, this phenomenon will not be experienced. Although there is yet considerable doubt whether the rate of thawing increases the amount of injury to vegetative tissues or organs which have been frozen, the evidence indicates that ripe apple and pear fruits suffer to a greater extent with more rapid thawing. At 40° F. frozen apples thaw with much less browning and visible breakdown than at a higher temperature.[31]

Hardiness of different tissues. The different tissues of a fruit tree vary in hardiness and they also change at different seasons of the year. It has been shown that when trees are in an actively growing condition, the cambium, young cortex, and sapwood cells are the tenderest, while when the tissues have matured, the pith in the twigs is the first to be killed, followed by browning in the sapwood and the outer or old cells of the cortex.[10] The notable point here is that cambium is most tender in the growing plant but relatively hardy when it is in winter condition. It has been determined that the dormant cambium was never found injured, "even after artificial freezing when the branches were subjected to a lower temperature than was ever recorded in the orchard." [43] This latter observation can sometimes be made with peach trees after a severe winter when a cross section of the limbs or trunk would look so brown or black that little or no hope could be entertained for saving them. The cambium may start into growth in the spring, however, and soon a new layer of xylem and phloem are formed, which begin functioning, and recovery of the tree takes place.

In the root, on the other hand, the cambium or the immature xylem tissue in the cambial region is the first tissue to be killed.[36] Carrick found that in the apple this was followed closely by the phloem while the cortex was somewhat hardier. Unless the temperature becomes quite low, the mature xylem and the pith are relatively little affected.[8]

Flower buds of the peach are recorded to be about as hardy as the cortex, cambium, and sapwood of the shoots in the latter part of summer, but during the winter they are the most tender of all the tissues above ground with the possible exception of the pith cells. Usually the leaf buds are more hardy than the flower buds, but instances have been recorded several times in which the leaf buds have been killed or badly injured while a portion of the flower buds have survived and fruit was produced, even in the absence of leaves. This is explained on the basis of lack of maturity of the wood tissues, while the flower buds reached maturity before the freezing occurred.

Rest period. That perhaps all plants have a more or less definite rest period has been established by a number of writers, notably Klebs in Germany, and Whitten [48] and Howard [28] in America.* This phenomenon can be observed with different varieties of the same kind of fruit by the early swelling of buds and time of starting into growth. Those who wish to plant grape cuttings in the greenhouse or bring twigs of fruit plants into a warm room in winter will soon observe that a rather definite date demarcates the time when growth will start. For the more southern peach-growing sections which are in the danger belt for spring frosts, varieties with short rest periods are desired, otherwise they will not complete their dormancy and development properly in the spring.[16] In order to shift the rest period to later in the winter a series of experiments were conducted by Whitten to cause the trees to enter their rest period at a later time, and hence to induce a correspondingly later awakening from this state. By means of late cultivation, it was possible to delay the rest period, and as a result the trees were a few days later in blossoming than was the case under normal conditions. This would be a dangerous practice in the north where a delay in maturity would tend to make the trees less mature and hence more likely to suffer from winter injury.

The blossoming period cannot be delayed by mulching frozen ground, or other practices designed to affect the root system only. Neither has spraying trees with whitewash or other material designed to reflect the light (and heat) proven satisfactory, although some slight benefits have sometimes been shown.

Various artificial means have been used to break the rest period of plants, among them low temperature. But it is only within recent years that it has been realized that such trees as the peach, nectarine, and others require an exposure to chilling temperatures for normal flowering. In Georgia, California, and other sections where the winter temperatures may not reach this point very late blossoming results in some years. Chandler and Tufts [13] demonstrated the same phenomenon with the apple, as well as peach and other fruits in California, where the time of opening of leaf and fruit buds is determined less by the spring temperature than by the amount of winter-chilling weather. This is well illustrated by the following example. On October 1, 1930, two Early McIntosh apple trees were potted and placed in storage at −1 to 0 degrees C. They were removed and planted in the orchard beside untreated trees, one on December 23 and the other on January 26. As will be seen the treated trees were in bloom much in advance of those left under natural conditions. (Table 29.)

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* *Note.* The student should distinguish between "rest period" and dormancy. The latter refers simply to the entire period when the plant is without leaves and visible signs of growth activity.

TABLE 29. EFFECT OF CHILLING TEMPERATURE UPON THE BREAKING OF THE REST PERIOD IN EARLY MCINTOSH APPLE TREES

(From Chandler and Tufts) [13]

	Leaves 1 cm. Long	*Leaves 2–4 cm. Long*	*All Flowers Open*
Tree taken from storage Dec. 23	Jan. 20	Feb. 2	Feb. 25
Tree taken from storage Jan. 26	Feb. 11	Feb. 18	Mar. 6
Tree left in orchard	Mar. 6	Mar. 13	Apr. 2

It is of interest to note that flower parts develop slowly within the bud even during cool weather at about 40° F. or above, but much more slowly than buds exposed to cold weather during the rest period and then exposed to warmer temperatures. Chandler and Tufts conclude that "at any time after there has been chilling weather enough to break the rest in part, but before there has been enough to break it completely, buds on long, late-growing shoots will respond more slowly to warm periods, in development, in swelling, or in opening, than buds on shorter early-maturing shoots." [13]

More specificially, Chandler, *et al.*,[12] noted that if there are not at least two months during which the temperature averages below 48° F. opening of the buds will be considerably delayed and they will open very unevenly. Spraying in early January with linseed oil, seal oil, lubricating oil, or dinitro-o-cyclohexylphenol in oil, is effective in promoting early flowering after warm winters, particularly with apples and pears.[4, 12]

Most of the common peach varieties, and varieties of nectarines, tend to have slightly shorter chilling requirements than the average variety of apple. The Mayflower seemed to require the most chilling of any California varieties before its buds would open normally, and it shed its fruits the worst. This has also been noted in Georgia.

Similar observations have been made with practically all of the deciduous fruit trees in the warmer districts of California.[4]

Variation in hardiness of fruits. While the varieties within any given kind of fruit vary widely in hardiness, yet there is rather marked difference between species and genera of the common fruits. Apples as a class are the most hardy of the commonly grown tree fruits, followed by the American plum, Japanese plum, sour cherry, European plum, pear, sweet cherry, apricot, and peach. The currant and gooseberry are hardier even than the apple. There is so much variation in different localities and in different seasons, however, that such a classification cannot be consistent. The evergreen fruits, such as citrus, persimmon, and others found in the subtropical regions of the United States are much more tender than any of the deciduous species.

Kinds of Injury

The interpretation of cold weather injuries is not simple. Sometimes the manifestations are so varied and extend so long after the time when the low temperature occurred, and so many other complicating factors may be involved, that accurate diagnosis is often baffling. In other cases the injuries from cold are quickly recognized. After a winter of abnormally low temperatures the student should spend much time in the field and enlarge his personal experience as much as possible. No two seasons are alike, but such follow-up observations are invaluable for future use.

For convenience, the kinds of winter injury to fruit trees and other plants may be grouped into three general classes: (1) bud injury; (2) injury of the woody parts above ground; and (3) root injury.

Bud injury. While many factors are involved in winter killing of plants or their parts, the conditions under which the buds are killed may be roughly placed in the three following categories: (1) When buds go into the winter in an immature condition and low temperatures occur early (December); (2) when mature buds are subjected to such low temperatures during the winter that their tissues are killed; and (3) when unseasonably warm weather in winter or early spring is followed by very low temperatures.

Of the tissues of the flower buds the pistils are the most tender and are frequently killed when the other parts remain unhurt. Such blossoms may expand, especially if the injury occurs just prior to bloom, but of course they can produce no fruit. If the entire bud is killed, the tissues throughout turn brown and the bud dries and falls from the tree in the spring in the case of most of the stone fruits, or it may persist for a time with the apple and pear. Havis reported cases of the brambles where the stamens were killed and the pistil remained alive and fruited normally. This is unusual but typical of the idiosyncrasies of injuries from cold.[24]

Not all the varieties of fruit which are tender in the bud are also tender in wood, as may be illustrated by the Elberta peach, but generally this is true.

Winter killing of the flower buds of the apple is rare, but has been reported on various occasions.[25, 47] In some such cases the axillary leaf bud will continue the growth of the spur, and before the season is over it is difficult to detect that flower buds had been formed. In others the terminal flower bud is killed (particularly in Jonathan) or entire spurs are killed. The authors observed a considerable amount of flower-bud killing of the apple after the winter of 1935–36 but none after the winter of 1917–18 throughout New England when the temperatures were lower.

Like the apple, the flower buds of the pear are not likely to be injured, but the spur itself may be killed, with the consequent destruction of the flower buds.

As a rule, the more commonly grown varieties of the sour cherry are hardy in bud as far north as central New England, except in very extreme winters when low temperatures follow after the buds have swollen. On the other hand, Macoun reported that in the fruit-growing sections of Canada the cherry, like the European and Japanese plums, is injured more or less every winter when not protected by some body of water.[32] Similar injury to the buds of Early Richmond was reported in Wisconsin after the winter of 1917–18, and Roberts [39] states that failure to secure a crop of cherries in Wisconsin is more apt to be due to this cause than to any other trouble. This was also true in Ohio and adjoining states after the winter of 1935–36. Gardner reports that in the Montmorency cherry there exist certain bud sports which show a much greater susceptibility to low-temperature injury than the standard Montmorency strain. The flowers of these aberrant strains are particularly injured by low temperature shortly after development begins within the bud either before or after the end of the rest period.[20]

The sweet cherry is much less reliable than the sour; in fact it is not much hardier than the peach. After a severe winter in Ohio the varieties which were most hardy were Bing, Yellow Spanish, and Governor Wood, while those most severely damaged were Lambert, Windsor, and Black Tartarian. The flower buds of all varieties were killed at a temperature of −15° F.

Varieties of the plum vary widely in their hardiness.[17] Many of the American species (such as *Prunus nigra*) are very hardy, while others are not. Some varieties of *P. salicina*, such as Burbank, also are reasonably hardy in the northern latitudes. The European plums (*P. domestica*), while not tender, are usually not so hardy as other species and are not widely grown as far north as New England and Canada, although this again is largely a varietal characteristic. After the record winter of 1935–36, Havis recorded that a full crop of plums was produced on Nixie, Freestone Goose, Crittenden Damson, and French Damson, while all blossoms were killed on Reine Claude, Burbank, Clyman, Hall, French Prune, Arch Duke, Agen, Imperial Gage, Gueii, and General Hand.[25] It will be noted that the hardiest ones were either varieties of American species or *Prunus domestica* var. *insititia* which is hardier, in the main, than *P. domestica.*

The buds of the peach are the most tender of any of the tree fruits commonly grown in the northern United States. Varieties differ markedly and no definite point of injury can be stated, but a temperature from −18° to −20° F. is likely to destroy most or all of the flower buds. A temperature several degrees higher may be equally destructive under some conditions. The stage of development of the buds is also important. As the tree enters the dormant season the buds become progressively more resistant to low temperatures.[16] The degree of cold which will kill all buds varies thus according to the time at which the low temperatures occur, and in accordance with the temperatures immediately preceding. When the buds are coming out of the rest period in late winter, warm temperatures make them more susceptible to injury in case low temperatures follow. Even buds still in the rest period seem to become more active physiologically, and more tender when subjected to the above conditions.[6, 30]

Grapes have been injured seriously in several of the winters of low temperature. In general varieties of *V. labrusca* or *vulpina* (*V. riparia*) origin are relatively hardy and those more closely related to *vinifera* are tender. Some varieties are quite tender in the bud and others are also tender in wood.[21] It will be remembered that the bud of the grape is compound. Clark reports that with most varieties the primary bud was definitely more susceptible to low temperature than either the secondary or tertiary.[14] Such varieties as Agawam, Dutchess, Golden Muscat, Niagara, and Wilder are usually tender. Concord, Worden, Fredonia, Moore Early, and Caco are much hardier. Such varieties as Beta, Suelter, and Dakota have proved hardier under Northern Plains conditions.

Varieties hardy and tender in wood. Reference has already been made to varieties hardy and tender in bud; a like classification on the basis of susceptibility of the wood to injury is briefly noted. Varieties fall roughly into three groups: those distinctly hardy, those relatively tender, and those occupying an intermediate position. Considerable variation often exists within a variety as a result of such factors as extent of the crop, age, cultural treatment, and latitude in which the fruit is grown. The classification which follows deals chiefly with some of the better-known varieties. More extended information, concerning both old and newly introduced varieties, can be obtained at the various agricultural research stations.

The apple. It was concluded from surveys in Maine that definitely nonhardy varieties in that state include: Baldwin, Gravenstein, Ben Davis, Stark, Northern Spy, Tolman Sweet, St. Lawrence, King David, and Winter Banana. Those that were hardy were: Cortland, Macoun, McIntosh, Milton, and Oldenburg.[46] In New York, the relatively tender varieties include Fall Pippin, Hubbardston, Fallawater, Roxbury Russet, Sutton Beauty, Stark, and Rhode Island Greening. On the other hand McIntosh and its family, including Melba, Early McIntosh, Cortland, Macoun, are rated as quite hardy. In that state Northern Spy, Rome Beauty, and Jonathan were found to be less hardy than the varieties of the McIntosh and Delicious families, but much hardier than Baldwin. Crab apples are much hardier than the standard commercial varieties.

The pear. In pears the varieties cannot be so distinctly grouped as in the apple. Two varieties represent the extremes, Beurré Bosc being tender and Seckel hardy. Flemish Beauty, which is now relatively little grown, is probably as hardy as Seckel. The pear as a group contains varieties hardier than the tender varieties of apples, although in general the varieties of the European pear (*Pyrus communis*) are less hardy than the apple.

The peach. Knowlton [29] has listed peach varieties of varying hardiness of wood. The most tender were Belle, Billmeyer, Hiley, J. H. Hale, Krummel, and Late Crawford. The hardier were: Banner, Buttercup, Carman, Eclipse, Golden Jubilee, Greensboro, Kalamazoo, Rochester, and Smock. The temperature dropped from 50° to −16° F. in 12 hours accompanied by a high wind. Under the same conditions Delicious, Grimes Golden, and Golden Delicious apples suffered most and Rome Beauty, Oldenburg, and McIntosh least.

The plum. Experience at Geneva, New York, has indicated that the European varieties Gueii, Quackenboss, and Yellow Egg are particularly hardy. Stanley and Italian Prune are reported both in New York and Ohio to be hardy. On the other hand, Hall is rated relatively tender. The varieties of the *insititia* group as well as the hybrids between the Japanese and native species are very hardy. Japanese varieties vary considerably in hardiness. Abundance and Burbank at Geneva proved to be hardier than many of the newer kinds.

The cherry. At Geneva, New York, Montmorency sour cherry was injured less than English Morello during the winter of 1933–34. The Duke varieties are somewhat less hardy than the sours.

Injury to the woody parts above ground. While a loss of the flower buds is a serious economic factor, the injury that may occur to the tree itself is more destructive in its nature. Winter injury to fruit trees may take several forms, some being rather characteristic of one section and some of another, or all forms may occur in a given region. The following are the more important types of such injury: killing of the terminal growth of the twigs; killing of patches of tissue on the limbs or body of the tree; crotch injury; "black heart"; collar rot; frost cracks; bark splitting and sun-scald.

The killing of the terminal growth of the twigs. This is common with many kinds of fruit trees in a severe winter, particularly with the peach, but may occur with the hardier kinds. It is more likely to occur if the growth has continued late and has not matured well. It may also be due to an inherent tenderness of the variety. The result of this injury is much the same as from cutting, or shearing back the terminal growth; that is, the uninjured buds nearest the terminal will make a longer growth than if no injury had occurred, while the proximal ones are likely to remain dormant.

Dead areas on trunks and branches. The killing of patches or areas of bark on the limbs and trunk is also a common type of injury. This will first appear as a purplish or darkened area, often somewhat sunken and which eventually dries and cracks. If such patches are tapped with a hard instrument they produce a "dead" sound as compared with uninjured parts. It is thought that considerable of the black-rot canker (*Sphaeropsis malorum*, Peck) so common on the apple in some sections is due to the entrance of disease spores through openings in the bark caused by the splitting or drying out of the dead areas. This type may also take the form of what is sometimes called "frost cankers."

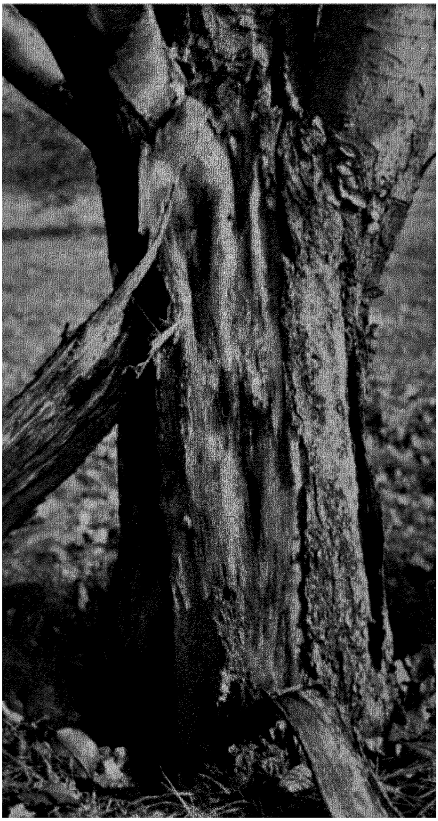

Fig. 74. Delicious apple variety showing common type of winter injury following winter of 1935–36.

Large areas of injured or dead bark on the trunks of older trees are also common in the northern sections, particularly on Baldwin and Tompkins King varieties. (Fig. 74.) They are the result of much the same set of conditions as produced the dead areas on smaller branches. It is more serious, however, for there is opportunity to remove an injured branch but it is difficult to repair damage to the trunk. The bark in this case will loosen and come off. Unlike sun-scald this injury does not occur on any particular side of a tree.

Crotch injury. This is characterized by killing of the tissues in the forks or crotches of both large and small branches. The injury may be restricted to a small area or it may be more extensive. Several theories have been proposed to account for it, such as drying out, occurrence of ice at these points, and immaturity of the wood. The latter, according to Chandler is the principal, if not the only factor involved. The tissue most recently formed and hence the most tender is near the base of the branches and near the bottom of the trunk of the tree. This tissue becomes more hardy and mature as the season advances. Hence, if very low temperatures occur early in the winter, it is the first to be injured.

Collar rot. A type of winter injury which has long gone by this descriptive name is prevalent in many areas. The injury may partly or entirely encircle the crown of the tree and may also extend downward to the roots. Such varieties as Grimes Golden, Gravenstein, and Tompkins King are particularly susceptible and for this reason they are often top-worked on a more resistant variety. "Collar" or "Crown girdle" of peach, and to a lesser extent of apple, are extremely frequent causes of loss of trees in the various sections of the country. For example, collar girdle of peach in Georgia is one of the most important sources of loss of trees in the orchard. This appears to be the result of rather sharp drops in temperature down to not more than 16° to 18° F.

This trouble need not be confused with "body blight" (*Bacillus amylovorus*) because in the latter case the bark tightens to the tree instead of loosening.

There is a collar rot which occurs primarily on the Grimes Golden variety due to a disease common to the peony. It became epidemic in Indiana in 1933 but had been known for some time. This is caused by a soil-inhabiting fungus *Phytophthora cactorum.* In many orchards between 43 and 67 per cent of Grimes Golden trees were partially and completely girdled in that state. The disease not only attacks the trunks but also the bases of the scaffold limbs. It is recommended that susceptible varieties (Grimes Golden and Rome Beauty) be sprayed with a 16-16-100 Bordeaux mixture to which is added a gallon of dormant oil, before the delayed dormant stage. The canker should be cut out and the wound painted over with Bordeaux paint.[3]

Frost cracks. The splitting of bark and wood of trees often accompanies low temperatures. These cracks may extend up the entire length of the trunk and follow up one or more of the main branches, or they may be quite short. These cracks usually draw together as the temperature rises. Such scars are common on sweet cherry trees. When they occur on young trees the bark may loosen nearly or quite around the tree. While they usually callous over rather rapidly, young trees with excessive injury should be replaced. This occurrence with young or moderately young trees may occur as readily during a sudden cold night of early autumn as during winter or spring, particularly if they are quite immature.

"*Black-heart.*" A condition which is well described as "black-heart" is found in sections where winter injury is of common occurrence. The inner wood is darkened, often a shiny-black, while the cambium and bark remain alive. As a result, the tree continues growth and rapidly forms a new layer of xylem and phloem. Nursery trees, particularly pears, are frequently black-hearted in some sections, and they may make a stunted growth or soon recover, depending on the extent of the injury and on the growing conditions immediately following planting. In the main, they should be discarded as undesirable. Mature trees in some sections are often in this condition throughout their lives with no apparent incapacity.

By histological examination Steinmetz and Hilborn [43] noted that "The effects of low-temperature injury to *Pyrus malus* L. are apparent first as death of the protoplasm in the parenchyma cells. This is followed by an occlusion of the vessels by a substance resembling wound gum. The killed parenchyma cells and occluded vessels together form what is termed 'black-hearted wood.' "

Bark-splitting. Splitting of the bark of the trunk has been a rather common form of winter injury.[35] The bark may curl back, making a rather wide wound. At the same time the trunk may split, often into the center. The Greensboro peach in New Jersey is reported to be susceptible to this type of injury. It has usually been recommended that the bark be tacked down as soon as injury is observed, but despite this treatment much loss occurs.

Sun-scald. This type of injury occurs on the southwest side of tree trunks and large branches. It is due to the warmth of the sun exciting activity in the tissues, alternating with low temperatures at night. To avoid the injury the trees are often whitewashed or shaded by boards or barrel staves on the exposed side. When the injury has occurred the dead areas should be cut out with a smooth cut and the wound covered with tree paint or bridge-grafted when necessary. It is best to have the wound painted above and below since callousing does not occur readily on the horizontal edges of a wound.

Bartlett and Beurré D'Anjou pears have been found to be particularly susceptible to sun-scald, while Comice, Easter, and Flemish Beauty are injured less.

Root-killing. This form of injury is extensive at times in the northern fruit-growing regions, especially in winters when the ground is bare of snow. It is well known that bare ground will freeze much deeper than when the surface is protected by some sort of cover, but no cover of vegetation is as effective as a deep snowfall which lies on the ground throughout the winter.[8, 18, 19] Such hardy varieties as McIntosh and Wealthy will be root-killed as readily as the more tender sorts, like Baldwin and Wagener, in a snowless winter, although the trunks and branches of the latter varieties would show injury while none might appear on hardy sorts.

Chandler has shown that the roots are the tenderest part of the tree, and that the portions nearest the crown are the more resistant, while the smaller remote rootlets are the most tender. From his experiments he concludes that apple roots will be killed at about −3° C. (+26° F.) in summer when they are tenderest and at about −12° C. (+10° F.) in late winter with rapid freezing, this result varying somewhat with conditions. He also showed that French crab stock is less hardy in the roots than the scion roots of such varieties as Ben Davis; that "Marianna plum roots are more hardy than Myrobalan roots, and Mahaleb cherry roots seem slightly more hardy than Mazzard roots." [10]

Trees whose roots have been winter-killed usually start growth in the spring, but the leaves are small and both the leaves and flowers are likely to wilt shortly after bloom and the tree show signs of dying, or the death of the tree may be slow, especially when a portion of the root system recovers. As in branch injury all sorts of manifestations occur, from early death to death 2 or 3 years afterward.

Potter found that the rate of thawing did not affect the injury resulting from low temperatures. However, drying of the roots until about 5 per cent of the total moisture was lost reduced the injury to one-half that suffered by turgid roots. Scion roots from hardy varieties did not influence the hardiness of the understock on which they were worked. But he found that the scion roots of Duchess and Hibernal were hardier than those of other rather hardy varieties.[36]

The loss of cherry trees, both sweet and sour, is largely a matter of root injury although trunk and branch injury occurs in years of prevalent low temperatures. The loss from root trouble is largely concerned with poorly drained soils. But another factor of importance is the understock. Losses are much more severe with trees on Mazzard than on Mahaleb stock. But despite this fact Mazzard is usually preferred for both sweet and sour cherries.

There are various manifestations of root injury in the cherry: (1) The trees may be killed and no foliage appear in spring. (2) The trees may die at time of blossoming. (3) They may produce foliage and then die upon the advent of hot, dry weather. (4) Trees may die after one, two, or three years at any of the above states. Others outgrow the injury.[22]

Factors involved in injury from low temperature. Many factors are involved in injury from low temperature and it is often not easy to diagnose the trouble. A certain degree of temperature may cause extensive injury at one time and none at another. Previous droughts, or drought at time of injury, defoliation from any cause, a heavy crop the previous season, delayed harvesting of a crop, the variety, the seasonal conditions which precondition the maturity of a plant, as well as soil and other related factors are all involved. Just how to separate and evaluate each is often difficult, and it is easy to draw erroneous conclusions.

Soil and site. The selection of a soil and site are discussed elsewhere, but their special relation to winter injury may be referred to again.

Probably no other factor is so closely related to the permanence of a fruit plantation as the soil type. Orchards on unfavorable soils, that is, those that are excessively wet or dry, are unlikely to survive for a long period of time. That "wet feet" and injury from cold are interrelated would appear evident in many cases, and it is not an easy matter to separate them.

Likewise the site or topography of the land is of prime importance. Coves, "draws," depressions, or low-lying land are likely to be much colder than higher elevations. Wind-swept prairie regions are particularly cold in winter as compared with those in the vicinity of large bodies of water. Altitude, as measured by elevation above sea level means little or nothing, but elevation above the land or water immediately adjacent means much or everything. This is due to the tendency of cold air to flow down to lower levels or air-drainage.

Orchards are occasionally found on level or low-lying areas or in canyons that are particularly free of frost and freezing damage. This is because of protection by fogs, air currents, nearness to water, or other like factors.

Windbreaks or woodland on the lower or leeward side of an orchard, so that cold air banks against them, are particularly objectionable. The rows of trees nearest such "shelter belts" are most likely to be damaged during a cold period.

Maturity of tissues. Of the factors involved in winter injury probably none is more important than maturity of the plant and its respective tissues. This has been established both experimentally and from wide observation.[2, 5] Anthony, *et al.*[2] stated after the severe winter of 1935–36 that the survey they conducted seemed at first to lead only to conflicting evidence until it was realized that tree maturity was the one common factor throughout all areas. Some of the orchards examined had been previously subjected to temperatures 10 to 20 degrees lower, and without damage. The previous crop (1935) had been a heavy one, and an unseasonable freeze in early October injured leaves and checked the normal maturing process. Then on January 20 the temperature dropped suddenly from above zero to 10 to 20 degrees below. As a result, trees either too high or too low in vigor suffered most.

It has been observed that the hardiest varieties mature early in the season. Macoun studied the effect of winter on a large number of plants at Ottawa, Canada, for a period of 22 years, having under observation over 3,000 species and varieties, many of which kill back more or less every year. Plants exhibiting this reaction are native to regions having a longer growing season than that at Ottawa, where they consequently mature too late and the wood is not thoroughly ripened. He, therefore, concluded that a tree or shrub capable of withstanding a test winter at Ottawa must ripen its wood early.[33] Not only do the more mature trees exhibit greater hardiness, but they also become hardier as the winter advances, until they again respond to growing conditions as spring approaches. While writers have commonly assigned the reason for lack of hardiness to a higher moisture content of the tissue, Chandler showed that, with the exception of the cambium, the tissues contain as much moisture later in the winter, when the plant is hardier, as at the beginning of the dormant period.

An additional point of evidence that maturity and growth conditions of the previous season affect the resistance of trees to cold is the observation that trees having their foliage injured or destroyed by insects or spray burning suffer serious killing of the wood.[44] Also the inner surface of branches, which possess less foliage, is nearly always more tender than the exposed sides. Trees which were top-worked during the previous season are also likely to be injured by a cold winter, as compared with others, side by side, which were not so treated.[49]

Relation of crop the preceding season. It has been observed in various sections of the country that trees which fruit heaviest are most likely to be injured by low temperatures during the winter immediately following. This observation was made repeatedly after the severe winter of 1917–18.

Macoun described a row of Wealthy apple trees (21 years old) at Ottawa that behaved in this way. Of 14 trees, the 8 which bore a medium to heavy crop in 1917 were killed or badly injured, while the 6 bearing either a light crop or none at all came through the winter in good condition.[34]

In New York state and in New England it was noted that hardy varieties of the apple were killed more readily than such tender sorts as Baldwin, in cases where the former had set a heavy crop the preceding season while the latter had not. This result, as indicated earlier, is verified by the fact that well-thinned peach trees seemed to be more resistant than unthinned ones which have borne a heavy crop. The average percentage of peach buds killed on thinned trees was 35.4; the average on unthinned trees was 51.4.[9]

Again, if the fruit crop is not harvested, as with grapes, or at least until very late, the canes or wood are much more likely to suffer injury from cold, even in a year of only moderately low temperatures.

Partial defoliation. Partial defoliation, occurring chiefly as a result of insects or diseases is known to result in greater injury to flower buds of the peach, and even to greater twig injury, during periods of low temperatures.[15] At Beltsville, Maryland, the injury to flower buds was greater on those branches having the smallest leaf-fruit ratios during the previous summer. For example, with 10 leaves per fruit all buds were killed, while at the same temperature, with 30 leaves per fruit, only 50 per cent were killed.[16]

Orchard Practices

Culture. The type of culture is often interrelated with soil, site, fertilization program, and other factors. Here again it must be repeated that circumstances which result in immaturity of wood are likely to contribute to injury from cold. If, for instance, a soil management program results in high moisture and nitrates throughout the middle and latter part of the season, winter injury to the aboveground portions might be more serious than in other systems of culture. On the other hand, one of the striking cases observed after 1935–36 concerned some Wealthy apples, a portion of which had been mulched for several years with manure and straw. The alternate trees in the rows, fillers, were left in sod. Almost without exception the bark was entirely loose around the trunks of the "fillers" and in good condition around the permanents. Likewise following the winters of 1903–04 and 1917–18 many trees in mulch survived when those in cultivation were injured.[2]

Trees in clean cultivation usually exhibit more injury, particularly root injury, than those where a cover crop is used. Even orchards where a "weed-hog" (a type of spring-tooth cultivator) was used seemed to suffer more than where the sod was undisturbed.[25]

Late cultivation has often been cited as inducing injury to apple, peach, and other kinds of fruit. The limits of "too late" have never been strictly defined, but the tendency is to stop cultivation earlier than formerly for this as well as other reasons. In general, it may be said that cultivation should cease at least by the middle of August in most districts where a two-cover-crop system is followed. A cover crop should also be sown at the time of last cultivation, since it has a twofold function in relation to winter injury: (1) by serving to withdraw any excess moisture in the soil, hence aiding in the maturing of the tree, and (2) by acting as a mulch to prevent such deep freezing and alternate freezing and thawing as would occur if the land were bare.

Use of fertilizers. The use of nitrogenous fertilizers in the spring have rarely been mentioned as contributing to winter injury. Trees of low vigor which have not been fertilized would be much more subject to such a result. Neither is there evidence on most orchard soils that a complete fertilizer or any special element has contributed materially to hardiness. At the time of writing there is an orchard of Baldwin and Stayman Winesap trees at the Ohio Station which suffered some injury in the winter of 1935–36. Outstanding is the unfertilized row which shows greater injury and almost no recovery as compared with the fertilized trees. Neither the complete fertilizer row (19 trees) nor the one receiving nitrate of soda and muriate of potash in the spring, appear superior to the rows which receive nitrogen only.

It is significant that when the first issue of this book was published,[23] no mention was made of the use of fertilizers in the fall. It was only about that time that such a practice was begun. This at once raised the question of possible injury during winter if nitrate of soda, sulfate of ammonia, or calcium cyanamide should be applied from mid-September to the first of November. After 16 years' experience with this practice the authors have found no authenticated cases of injury in Ohio following fall fertilization. On the other hand, certain experiences in New Hampshire gave some indication that the use of Cyanamid in the fall resulted in extensive injury to McIntosh, Delicious, and Winter Banana, although the evidence cannot be considered conclusive.[38, 45]

Until more conclusive evidence is at hand, the practice of fall fertilization is likely to be continued except, perhaps, in the northerly fruit-growing sections.

Pruning. After the past two or three "test" winters it has been observed that trees pruned just prior to the low temperature were much more severely injured than unpruned ones, and the heavier the pruning, the greater the injury. This was first observed by the writers on an extensive scale following the winter of 1924 at Chardon, Ohio. A number of apple trees had been pruned, and the work was interrupted by the cold weather. Without any other variable entering the situation, the pruned trees were so badly damaged that many were removed, while the unpruned ones were unhurt.

Again, after the severe winter of 1935–36, a row of apple trees which had been top-grafted in the spring of 1934 was pruned to partially eliminate the wood of the undesired variety. Another group of top-worked trees of the same age and varieties were left unpruned. All of the pruned trees were so severely winter injured that they died during the summer, while practically no injury was sustained by the unpruned trees.

Example after example can be cited to illustrate these extreme effects, as well as injury near and below a pruning wound. No clear and satisfactory evidence has been produced as to the exact cause of this phenomenon.

In the past it has been customary to begin pruning after the completion of the fall work, that is, in December or early January. This is purely a matter of convenience and a means of maintaining a better labor distribution throughout the year. In the future those who do this must furnish their own insurance, for any amount of pruning just before very cold weather is likely to take its toll in dead or injured trees.[37]

Treatment of frozen trees. Great care must be exercised in treating frozen trees, or the injury may be accentuated rather than reduced. The pruning of winter-injured trees calls for moderation rather than "dehorning," and the operation should not be hastened but rather delayed until the probable injury can be determined. Not infrequently death has followed the heavy pruning of injured trees, while those that were unpruned eventually recovered. In some seasons the peach is injured to such an extent that the buds are delayed in starting although the wood is not killed. This situation calls for careful observation lest live wood be cut away and the tree unnecessarily reduced.

In addition to proper pruning, it is also advantageous to apply a quickly available form of nitrogen as a means of stimulating growth. Cultivation of tilled orchards should begin early. Sometimes other complicating factors enter the picture, such as years of extreme drought either before or after the winter injury, and disease or insect troubles may add to the devitalizing effect.

Special repair work may also be desirable, such as bridge-grafting, or inarching, and cleaning and disinfecting wounds.

If the bark has loosened and rolled but is still alive it is well to tack it back into position as soon as possible. It may not unite with the wood immediately, but new xylem and phloem may be laid down in the bark so that it renews functioning and natural repair may go on. Sometimes two, three, or more cambial layers may be laid down within the bark and a confused layer of tissue is produced for a time.

Use of hardy under and intermediate stocks. This subject is treated elsewhere but it may be repeated that such hardy varieties as

Hibernal, Haas, Virginia Crab, and Antonovka, are being widely considered as a means of avoiding the wholesale destruction that has too frequently visited the apple orchards of America. The near future promises more specific information on this important problem.

Winter injury of small fruits. Species and varieties of the brambles vary widely in their susceptibility to low-temperature injury. Furthermore, varieties which have proven hardy in the north where the winter is continuously cold may prove tender farther south where the canes are not well matured when they go into winter, or where warm spells in the winter excite early activity within the plants. Hardy sorts of the red raspberry are Latham, Chief, Herbert, and Viking. Cuthbert is moderately hardy. Blackcaps are usually considered less hardy than the reds. Plum Farmer, Logan, and Cumberland are among the hardier blackcaps.

Of the blackberries Eldorado is reasonably hardy and Snyder quite so.

Gooseberries and currants are among the hardiest of fruits and rarely experience winter killing.

The loganberry, dewberry, boysenberry, youngberry, and some others are of questionable hardiness in the northern states. The lowbush blueberry *Vaccinium pennsylvanicum* is slightly more resistant to cold than *Vaccinium corymbosum*, the highbush blueberry. It is assumed that the blueberry relies on snow protection rather than great hardiness in Northern regions.[7]

The red raspberry may be injured because of delayed maturity or, in the spring, because the plants come out of the dormant season too early. Immaturity of canes may be due to too late cultivation, excessive fertilization, or too high soil moisture content in the fall. This injury may occur irrespective of the natural hardiness of the variety.[41]

Strawberries are often damaged from heaving of the soil unless mulched. Much of the so-called "black root" of this fruit is a result of low temperatures and is largely prevented by mulching or by a heavy covering of snow.

Vigorous, well-rooted strawberry plants which had not borne fruit were less injured than those which had borne fruit. Young runner plants which were not well rooted did not survive as well as those well rooted.[42]

Strawberry varieties have been found to differ appreciably in the amount of winter injury and their ability to recover. In Oregon, Corvallis, Blakemore, Redheart, and Narcissa were hardier than Marshall, Ettersburg 121, and Wickson.[42] In some hardening studies in Minnesota the order of decreasing capacity was Gibson, Mastodon, Wm. Belt, Chesapeake, Progressive, Klondike, Missionary, Premier, Dunlap, and Aroma.[1]

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NUTRIENT DEFICIENCIES AND PHYSIOLOGICAL DISORDERS

Within the last decade outstanding progress has been made in the study of nutrient deficiencies as well as in the field of the so-called physiological disorders. For some time past, a number of these disorders, not caused by a pathogenic organism and therefore often termed physiogenic, have had a rather disastrous effect, since neither the cause nor the control was known. Recently two outstanding examples of these disorders, namely, little-leaf and cork or drought spot, have been found to be due to a deficiency of two essential elements—zinc and boron, respectively. Consequently research has been undertaken with other physiological disorders whose cause and control are yet unknown, with the probability that marked success in determining the cause if not the control will eventually be attained. Certain other disorders such as apple scald are now successfully controlled by a procedure well known to all fruit growers.

Because of the obvious interrelation of nutrient deficiencies and the physiological disorders they are here discussed concurrently. The chapter is divided into two sections: the first consists of a description of those symptoms which characterize a deficiency of a number of essential elements. In addition the physiological disorders believed to be caused by these deficiencies will be discussed in connection with the particular element concerned. The second section considers those physiological disorders unassociated, at present, with the deficiency of any essential element.

NUTRIENT DEFICIENCIES

Research in this field has been conducted by means of tests demonstrating the effects of a deficiency of each of the essential elements in turn. The outstanding work of Wallace in England greatly stimulated this type of research. By the use of dwarf trees, grown in pots containing quartz sand, he was able to determine the effect of a certain deficiency, not only upon the growth of the plant but also upon its flowering and fruiting. Similar experiments in the United States have been concerned largely with young trees grown on vigorous understocks in the greenhouse, trees which would not flower for several years. Both types of research have been exceedingly valuable as an indication of the effects of a deficiency which are to be expected under field conditions. As a result attention has recently been directed to determining whether there are orchards, vineyards, and small fruit plantations where several of these deficiencies other than nitrogen occur naturally.

Symptoms of a Deficiency of Certain Essential Elements

The symptoms of the deficiency of certain essential elements are to be discussed in the following order: nitrogen, phosphorus, potassium, magnesium, calcium, boron, and zinc. These particular elements were selected for discussion because, in certain cases, they have been observed to be deficient in fruit plants under field conditions.

Obviously those processes within the plant which are dependent upon the supply of a particular element are the first to be affected by a deficiency. The rate at which these processes occur slows down, more or less in proportion to the extent of the deficiency, and, in consequence, the growth rate of the plant is soon affected also. The visible effects, those extreme symptoms which are particularly characteristic and are produced upon the stems, leaves, and even fruits, occur only as a result of the prolongation of the deficiency, often after the various cell processes have been considerably disturbed.

The symptoms usually observed have been derived largely from laboratory or greenhouse studies. Similar deficiencies, when found in the field, are usually less marked than those observed on plants grown in a nutrient solution which is completely lacking in the essential element. This is to be expected since some small supply of an element, though in many cases quite inadequate, is usually available in the field.

The various elements required for growth and reproduction may be divided into two groups, based on the portion of the plant in which the yellowing, chlorosis, or characteristic breakdown is first observed. In the first group, which includes nitrogen, phosphorus, potassium, and magnesium, these symptoms are first observed in the older leaves. In the second group which includes calcium, boron, and zinc, the younger leaves and younger stem portions show the first breakdown or chlorosis.

This difference in the location of the first yellowing, chlorosis, or necrosis of plant parts is essentially a question of the mobility of the elements concerned. If an element is mobile, it is translocated from the older to the younger portion of a plant whenever the supply entering the plant is materially reduced. Thus the characteristic yellowing is first observed in the older portion from which the element is translocated. On the other hand, if the element is relatively nonmobile, there is little translocation from the older to the younger portions, and thus the younger leaves and stems first exhibit the characteristic symptoms of deficiency.

Nitrogen Deficiency

The symptoms of nitrogen deficiency and the frequency of its occurrence are so well known that discussion here is unnecessary. The most important symptoms of this deficiency are given in connection with Chapter 7 on Fertilizers and Manures for the Orchard.

Phosphorus Deficiency

The most outstanding characteristic of phosphorus deficiency is the dark, grayish-green cast of the foliage and stems, a shade darker and duller than that of normal foliage.[6, 14, 43, 50, 52] As a result of the translocation of phosphorus to the apices of the growing stems, linear growth may continue until the supply of the element becomes seriously limiting, but finally the growth of the leaves and stems may become definitely restricted as in nitrogen deficiency, to which this deficiency shows some points of similarity.[50, 52]

In the English experiments, the yield was greatly reduced, due to the dying of buds.[50] The color of the fruits was dull and unattractive, and, as opposed to nitrogen deficiency, they lacked firmness and were undesirable commercially. Only under extreme conditions are such severe effects to be observed in the field; but peach trees in the Sandhill section of South Carolina have shown several pronounced symptoms of phosphorus deficiency, including less flower-bud development and a lower yield.[43]

Potassium Deficiency

The more important symptoms of potassium deficiency are given in connection with Chapter 7 on Fertilizers and Manures.

Magnesium Deficiency

The outstanding characteristic of magnesium deficiency in horticultural plants is the loss of chlorophyll, and subsequent browning and breakdown of the tissue between the veins, while the vascular tissue remains green.[6, 50, 52] The veins thus show a green, net-like form over a light green to yellow background. The older leaves lose their chlorophyll first. Certain areas along their margins are affected at first, but the yellowing and breakdown do not extend around the entire margin as in potassium deficiency. Plants tend to differ in the extent to which the loss in chlorophyll precedes the breakdown. In the apple a relatively large area of leaf tissue may quickly become brown and dried out while other fruit plants, such as the strawberry and raspberry, show considerable leaf yellowing before breakdown occurs. In the strawberry and currant the upper surfaces of the leaves may become tinged with red. Affected leaves may also show a characteristic curling and puckering. In the sand-culture experiments with fruit trees magnesium deficiency develops quickly, resulting eventually in the abscission of the leaves before the chlorophyll disappears from the tissue between the veins.

A few instances of magnesium deficiency have been reported in fruit plants in the field.[45, 51] Evidence is accumulating, however, to indicate that plants grown in acid, magnesium-deficient soils of light sandy texture such as are found along the Atlantic seaboard may show visible signs of magnesium deficiency. Bronzing or yellow leaf of citrus in Florida has been controlled by applications of magnesium.[45]

Calcium Deficiency

Calcium deficiency in pot cultures quickly shows severe effects. Because very little calcium is translocated from the older portions, the deficiency symptoms appear first in the young, growing tips and leaves.[6, 52] In the peach, chlorotic areas develop in the center of the leaf blades near the margins, and browning and breakdown occur very shortly. Of all the major elements, lack of calcium has resulted in the greatest restriction of root growth. In sand culture where calcium has been completely eliminated, the roots are short and the tips brown. New roots are usually short-lived, and the absorbing area greatly reduced.

Calcium deficiency of fruit trees has been reported in few instances in North America and not at all in England. It is not improbable, however, that in certain sandy soils along the Atlantic seaboard such a deficiency may occasionally occur.

Boron Deficiency

Peach trees in boron-deficient sand culture quickly show injury. Dark green water-soaked spots, exuding sap, appear on the growing apices about one inch from the end.[52] The spots enlarge, turn brown, and girdle the tip. The leaves beyond the necrotic area wilt and die. Buds that are developing farther back will, in turn, die at the tip, thus resulting in premature defoliation, receding from the stem apex backwards. The bark becomes brown, rough, and manifests many small cork-like patches. Boron-deficient grape seedlings in water culture were characterized in particular by not only a much restricted growth of shoots but also by a very poor root system.[28]

Cork and drought spot. The physiological disorders known as "cork" and "drought spot" are now known to be caused by boron deficiency.[17, 30] Since it was first described, other names such as "internal cork," "external cork," "corky core," "corky pit," and "crinkle" have been used to describe what, in reality, are manifestations of the same disorder. These terms characterize the effects upon the fruit. Two other terms "die-back," and "rosette," describe the effect upon the tree itself. The terms "cork" and "drought spot" are indicative of the area affected—"drought spot" specifying the more superficial injury. In reality, the origin of both types of disorder is the same, but the location of the affected portion and the severity of the injury depend upon the variety of fruit and the time of development of the disorder. The terms "internal" and "external" cork might well serve as more uniform, and yet distinguishing names for the disorder.

This disorder has been found in New Zealand, Australia, British Columbia, Ontario, and Northeastern United States, and in the Shenandoah-Cumberland and Pacific Northwest regions. In British Columbia the peach, pear, plum, and cherry are also affected.

When the spongy, brown spots are found within or near the core, the only external symptoms may be an uneven surface contour and a rubbery feeling when the fruit is compressed in the hand. The affected fruits may appear relatively normal in size and shape, and abnormally red in color. McIntosh fruits tend to fall prematurely. If the spots occur in the outer flesh the fruits may be corrugated, roughened, or depressed in spots, while the areas affected may be quite large, russeted, retarded in growth, and cracked.

The first stages of "dieback" are manifest usually in late summer. The young shoots may develop only small leaves which become chlorotic and abscise. On certain shoots also, the leaves may show a yellowish to bronze color with red veins, and marginal scorching especially near the tip. Beneath axillary buds dead vascular tissue may be observed. The area affected enlarges, and the shoot dies from the tip backwards. Portions of the bark of twigs over one year old may manifest an internal necrosis and show external pocklike areas similar to those observed in apple measles (internal bark necrosis). In addition, the young shoots may lose all but the tip leaves, thus developing the "rosette" appearance. These leaves are usually dwarfed, narrow, and brittle. "Dieback" and "rosette" do not usually appear except under conditions of extreme boron deficiency.

The available evidence indicates that many apple varieties may be affected by boron deficiency, although some appear to be more susceptible than others. In the Northeastern portion of North America cork is more frequently found on Fameuse, Cortland, and McIntosh. In Fameuse the fruits are apt to be deformed with considerable surface injury while McIntosh presents less surface evidence. The Ben Davis group of varieties is very seriously affected in the Potomac Valley, while Jonathan and Rome Beauty are occasionally affected. The Yellow Newtown is very susceptible in the Hood River Valley in Oregon.

The outstanding facts in regard to the occurrence of this disorder are as follows: [24, 29]

1. Cork develops on trees growing in soils in which for any reason the boron content is low in the region of rooting. However, the depth to which the roots extend, the texture, and the reaction of the soil are important in determining whether cork will develop on such soils.

2. It tends to occur in orchards located on shallow soils or under conditions which restrict the absorbing root surface. For example, in the case of dwarf apple trees grown in sand culture, cork developed as a result of raising the water table.[24]

3. Trees stimulated by the application of highly nitrogenous materials such as pig, poultry, and cow manure show greater injury. The injury is particularly severe if environmental conditions are conducive to water deficits during the growing season of the fruit.[24, 29] Thus vigorous trees on a shallow, light soil have shown considerable injury in dry seasons.

4. Orchards developing the cork disorder are usually grown in a soil high in calcium.[24, 27] Frequently the pH indicates neutrality or above, but not necessarily so.

5. In the case of the pear the greatest injury from cork occurred during the light rather than the heavy-bearing year, that is, at a time when the leaf area per fruit was large.

6. Greater injury appears to develop in locations deficient in potassium.[31]

Control. Reduction of the amount of injury, or complete recovery, have been brought about by applications of boron according to three methods, the first of which is preferable.[12, 27, 31]

1. Applications to the soil in the form of borax (sodium borate) or boric acid (crystals). Where it seems undesirable to apply sodium also to the tree, boric acid is preferable. McClarty, *et al.*[31] recommend the application of boric acid at the rate of 30 pounds per acre in a circle beginning 2 or 3 feet out from the trunk, and extending as far as the drip of the branches. The application is made in the fall or spring as in nitrogen fertilization. Only one application is suggested, as a too concentrated treatment may be toxic.

Hydrated borax when applied in New Zealand penetrated rapidly into the root zone of apple trees, and the boron content of the fruit was markedly increased in the same season as the application.[2, 3] Although there was rapid leaching of boron from the surface soil the first year an application of borax at the rate of 50 to 100 pounds per acre was sufficient to prevent drought spot for 3 years. Boric acid in New Zealand at the rate of ½ to 1 pound per tree did not give as long control as an equal weight of borax. Present evidence indicates that small annual applications may be more economical than comparatively large amounts applied less frequently.[3] In New York treatments increasing according to the age of the tree have been recommended, the amount ranging from 2 to 16 ounces of borax per tree.

2. Boron-containing sprays applied to the foliage. When the soils are high in lime, sprays are recommended instead of soil applications. When sprays are used, two are recommended, one at the calyx spray and the other 20 days later, using no more than 2½ pounds of borax to 100 gallons of water.[1] This may be combined with lime-sulfur. In fact, injury to apple foliage from borax was reduced by the presence of lime. It is probable that spray applications are required annually where the disorder is recurrent.

3. Injections of boric acid into the trunk and limbs of the tree. Applications in this manner are not desirable commercially since serious injury frequently results.

Apple measles or internal-bark necrosis. "Apple measles" or "internal-bark necrosis" is a physiogenic disorder which is possibly caused by boron deficiency,[53] although this has not yet been ascertained. The term "measles" arises from the fact that pocklike areas develop on the outer bark. These areas, $\frac{1}{16}$ inch or more in diameter are raised and circular. Due to the fact that the phloem shows spherical, necrotic areas, the term "internal-bark necrosis" seems preferable.[5, 23] The shoots tend to die back from the tips, and the leaves become bronzed and abscise, resulting in long, bare branches. The trees affected make little growth and frequently die.

Delicious and its mutations are found to be the most commonly affected, although Jonathan, Rome Beauty, and Stayman Winesap infrequently show some injury. McIntosh seems to be less exacting in its boron requirements.[23] In certain locations, heavy applications of nitrogen, by inducing vigorous growth, have accentuated the injury. The disorder should not be confused with other pox types of diseases.[5]

Zinc Deficiency

Several disorders occurring on different kinds of fruit and assumed to be unrelated were found in 1931 to be cured by treatment with zinc.[13] On apple and pecan trees the disorder had been called "rosette," on stone fruits and the grape "little-leaf," on citrus "mottle-leaf," and on the walnut "yellows." These names are descriptive of the principal manifestations of the disorder.

It may affect fruit trees of all kinds from Florida westward to California and up the Pacific Coast. Trees are affected in light as well as heavy soils, showing a wide diversity in geological origin and conditions of weathering. In general, it appears confined to the regions where the growing seasons are rather mild, although in the Wenatchee and Yakima Valleys in Washington it is severe on apples. It is prevalent on soils tending to alkalinity, which results in the fixation of available zinc, and may occur in many areas of the Southern states, where the zinc content of the soil appears to be very low.

Chandler states that all orchard trees grown in the valleys of California will show injury where zinc deficiency is severe.[13] He ranks the various fruits in decreasing order of susceptibility as follows: sweet cherry, apple, Japanese plum, Domestica plum, peach, walnut, apricot, avocado, citrus fruits, some grape varieties, and the fig. The pecan and pear are considered more susceptible than the walnut. It has been emphasized that not all rosette, mottling, or yellows is due to zinc deficiency, and that the only certain means of identifying the disorder is the response made by the affected plants to zinc treatment. He has recently summarized the deficiency symptoms as follows: [13]

> "The most dependable symptoms on deciduous trees are the rosettes of small, stiff, nearly sessile leaves in the first flush of growth in spring. These leaves may or may not be mottled and they never become more than one inch long or about 0.25 inch wide. From below them, further below on apple trees than on stone-fruit trees, shoots tend to start that may bear healthy green leaves throughout the summer, the appearance of the trees in late summer often being better than that of healthy trees, because they have not been bedraggled with fruit. Trees affected more severely may bear leaves on these later shoots more or less mottled, small, and abnormally shaped leaves toward the end of the seasons growth. . . . . Some trees begin to die back when they have been affected a year or two, others after many years. Spring rosettes of small leaves are rare on cherry trees and Persian walnut trees, and are not always shown by zinc deficient citrus trees. In fact, old, unpruned trees of all kinds rarely show rosettes of small leaves in spring except on suckers. In orchards of kinds such as the almond, that are pruned lightly so that the shoot growth is very short, it is often impossible to distinguish the symptoms of zinc deficiency from those of other influences, such as nitrogen deficiency, crown gall, or nematodes, that cause leaves to be small.
>
> "If any fruit sets on badly affected branches, it is mostly worthless and shows symptoms characteristic of the species. Peaches and Japanese plums, for example, are smaller, more flattened, and more beaked than normal ones; apricots are small and less flattened; lemons are small, oblong, and pointed. There is also a tendency for stone fruits to have brown areas in

the flesh and to break down early. Walnut trees bear small poorly filled nuts, with tough, somewhat pliable shells instead of normal brittle ones.

"There is always a reduction in the number of fruit buds on trees rather badly affected, but stone-fruit trees usually have enough flowers for a fair crop if a good percentage of them set fruit. Usually, however, nearly all the flowers fail to set on the badly affected parts of the tree. Often the upper part of the tree is badly affected and bears only a few abnormally shaped fruits, while the lower part bears normal foliage and at least a moderate crop of fruits, nearly all of which are approximately normal in appearance."

Several treatments have been very effective in controlling this disorder, some in one or more fruits, others in all.[13, 34]

Spraying the foliage with zinc sulfate at the rate of 10 pounds to 100 gallons, with half as much hydrated lime added, has given the best control with citrus trees.[34] It is moderately effective on apricot trees and grapevines. Zinc sulfate can be combined with lime sulfur at the strength used in foliage sprays, and zinc oxide can be combined with oil sprays. For grapevines Chandler recommends the spraying or swabbing after pruning with zinc sulfate at the rate of 2 pounds to a gallon of water.

Spraying with zinc sulfate in winter before the buds swell has been effective with apple and stone-fruit trees. The strength recommended is 25 to 50 pounds of zinc sulfate to 100 gallons of water. Spraying must be repeated each year for several years after treatment is begun on a badly affected tree.

The following treatments have now been practically discontinued in commercial practice: applications of zinc sulfate to the soil; zinc sulfate placed in holes in the trunk; zinc or galvanized iron pieces driven into the trunk and branches.

PHYSIOLOGICAL DISORDERS NOT ASSOCIATED WITH A DEFICIENCY OF AN ESSENTIAL ELEMENT

In this section the physiological disorders are divided into the following groups:

1. Breakdown disorders.
2. Disorders associated with accumulation or effect of gases.
3. Disorders associated with starch-sugar changes within the fruits.
4. Miscellaneous disorders.

The first group, the so-called "breakdown" disorders may be divided into two groups: one associated with the premature ripening of fruit, and the other with the effects of low temperature in storage.

Breakdown Disorders Associated with Premature Ripening

Breakdown of fruits occurs naturally at an advanced stage of maturity when the various life processes decline and finally cease altogether. Fruits which have thus become soft, the tissue mealy and more or less discolored, are said to have broken down. When the fruits reach this stage prematurely, for example, just after harvesting or in storage or transportation, serious losses may occur. The term "internal breakdown" is usually applied to this condition, although the terms "storage breakdown," "mealy breakdown," "old age decay," "physiological decay," "senescence," and "inherent internal breakdown" have been used to denote the same condition.

Internal breakdown. The first visible evidence of breakdown may occur just beneath the skin, near the vascular bundles, or in the core region. The flesh becomes discolored, soft, mealy, and of a dry consistency as opposed to the moist condition of soggy breakdown. Finally the skin may crack, exposing portions of the flesh.

Varieties differ in the area affected and degree of the breakdown. The Jonathan variety has shown a more pronounced tendency to premature breakdown than have other varieties such as Stayman Winesap, Rome Beauty, Delicious, Wagener, and the summer-ripening apples. Breakdown in Jonathan usually affects all but the core region or the flesh immediately adjacent to the stem. In advanced stages the skin becomes dull in color and the flesh soft and spongy.[33] A breakdown in mid- or late winter at the stem end of McIntosh occurs on fruit removed from storage to high temperatures. The breakdown manifests itself as a browning of the skin in the cavity or stem end. Later the flesh beneath becomes soft, and the skin cracks open.

Control of breakdown in Jonathan, as well as in other varieties, is brought about as follows:

1. Fruits picked in an advanced state of maturity naturally break down within a shorter time, other conditions being equal. The change in the ground color in Jonathan and other varieties is a reliable index of the proper stage of maturity. In Jonathan the fruits should be removed before the full yellow shade is attained.

2. Large fruits tend to break down more quickly than small ones since the larger fruits are usually a little more mature when harvested. Thus the oversized, best-colored fruits should be removed before the bulk of the crop. Trees with a light crop should also be picked earlier, since those having a large leaf surface per fruit reach maturity earlier.

3. Orchard practices resulting in oversized fruits indirectly shorten the period intervening between harvest and breakdown. These practices should be so adjusted as to prevent oversize. Severe pruning, overthinning, overfertilization, and even late irrigation are conducive to early breakdown.

4. Delayed storage hastens internal breakdown, largely in proportion to the degree of temperature prevailing. Thus fruit should be stored promptly at a temperature as low as 36° F. With a variety such as Fameuse which is not susceptible to low temperature types of breakdown, a temperature of 32° F. is preferable if it is desired to keep the fruit for some time.

5. Breakdown may quickly follow water core, soggy breakdown, bitter pit, and other disorders, depending upon the variety and the severity of the original disturbance. In Jonathan, Rome Beauty, and Stayman Winesap water core usually leads to rapid breakdown.

Core breakdown. Other names such as "core rot" have been ascribed to the softening and browning of the core region of pears. The area affected may extend into the surrounding flesh as well, with the tissues becoming soft, watery, discolored, and turning brownish or black. Practically all varieties will show this condition when the fruits are removed from the tree after the optimum picking date,[21] and obviously the longer the delay the sooner the breakdown sets in. Varieties are reported to differ in whether a general or a "core" breakdown occurs after the fruits have become overripe. This disorder is not to be confused with "brown heart" which is due to carbon dioxide injury. It is interesting to note that acetaldehyde seems to be at a maximum in the fruits at about the time breakdown develops, and seems to be closely associated with the development of scald and core breakdown.[19]

Peach breakdown. Breakdown of peach fruits will occur when peaches are stored for a period longer than from 2 to 4 weeks, depending upon the variety and storage temperature. The first stages of breakdown are manifested by water-soaked appearance of the flesh around the stone. The area affected gradually becomes larger and turns brown. The entire flesh gradually becomes brown, dry, mealy, and loses flavor.[20]

Although the fruits will show some breakdown when held at 31° to 32° F., a much larger amount develops at 40°. In fact, in the varieties Carman, Belle of Georgia, Hiley, and Elberta, it reaches serious proportions after only 2 to 3 weeks' storage. For this reason it seems preferable to store the fruits at the lower temperature, but even here care must be exercised that the period is not extended beyond the maximum storage life of the varieties which is as follows: J. H. Hale and Late Crawford, 4 weeks; Slappey and Elberta, 3 to 4 weeks; and Belle of Georgia, Champion, Hiley, and Carman, 2 to 3 weeks.[20]

Breakdown Associated with Low Storage Temperature

A low-temperature type of breakdown is associated with storage temperatures ranging from 29° to 34° F. It is called "soggy breakdown," a name which to a certain degree describes its characteristic appearance.[36] Soggy breakdown and soft scald, formerly discussed separately, are now considered to be manifestations of the same disorder.

Soggy breakdown. This disorder is only of serious consequence where fruits of certain apple varieties have been stored at a temperature below 35° F., and usually after having been kept at temperatures considerably higher, previous to storage.

The principal difference between the soggy-breakdown and the soft-scald types is the location of the area affected. In typical *soggy breakdown* the flesh beneath the skin, but separated by a layer of unaffected tissue, becomes watery, brown, and spongy. In the *soft-scald* type both the skin and the flesh immediately beneath the skin become watery, discolored, and soft. In both types the line of demarcation between the affected and unaffected tissue is sharp and clearly defined, a characteristic which distinguishes them from other types of breakdown. Specimens of the same variety may show both the soft-scald and the soggy-breakdown types.

The first evidence of soggy breakdown is the development of light-brown areas in the flesh, which shortly becomes soft and watery. The soft-scald type is manifest in irregular, brown, soft, blisterlike areas on the surface of the fruit. Oddly shaped patterns, frequently ribbonlike, may completely encircle unaffected areas. The affected portions, as well as the adjacent normal areas, tend to acquire a slightly alcoholic taste.[11, 38] In the soggy type the core region is unaffected except under extreme conditions; [11, 35, 39] in the soft-scald type the core line is not affected.

Apple varieties differ in their susceptibility to the two types of soggy breakdown. Those which are predominantly susceptible to the internal form are Grimes Golden, Winter Banana, and Wealthy. On the other hand, Jonathan, Northwestern Greening, Winesap, and Rome Beauty only show the surface soft scald, and it is believed that these varieties do not become affected with the internal type. Other varieties which develop the soft-scald type are Baldwin, Cortland, Northern Spy, Stayman Winesap, Golden Delicious, Wagener, Winter Banana, and Wealthy. Arkansas, Delicious, Ben Davis, and Willow Twig do not seem to be susceptible to soggy breakdown.

The following facts are concerned with the nature and occurrence of the disorder.[11, 35–39]

1. It tends to develop in fruits of susceptible varieties, stored at temperatures of 29° to 34° F. As a rule, the lower the temperature the more severely the fruits are affected. Northwestern Greening, which is the most easily affected, may be somewhat injured even at 36° F.

2. Varieties differ in the effect which the promptness of storing has upon this low temperature type of breakdown. Prompt storage of Northwestern Greening tends to increase susceptibility; in others, such as Grimes Golden, Golden Delicious, Winter Banana, and Wealthy, prompt storage decreases susceptibility.[35] In Jonathan the effect of prompt storage varies; fruit from one orchard, if stored promptly will be more susceptible, from another, more resistant. With considerable delay (5 to 10 weeks at 50° F.) before storing at 32° F., Jonathan, Grimes Golden, Wealthy, Winter Banana, and Northwestern Greening showed decided resistance to breakdown, but this delay is obviously not recommended as a control.

3. Fruits picked late tend to be more susceptible. The exact cause of this form of low-temperature breakdown is unknown. The injury seems to be associated with the transference of the fruit from a temperature in which a relatively high respiration rate occurs, to one in which the catabolic activities of the fruits are greatly restrained.[38]

The prevention of this disorder lies primarily in storage of susceptible varieties at a temperature of 36° F. or above, in which case they should be placed in storage as quickly as possible after picking. The fruits should also be picked at the proper stage of maturity.

Internal browning. Internal browning is another type of low-temperature breakdown, particularly characteristic of the Yellow Newtown variety.[4, 32] The disorder has been fairly serious in the Yellow Newtown region of the Pajaro Valley, California. The same type of breakdown has been observed in Yellow Bellflower and other varieties grown under the characteristic environmental conditions of that region. A similar injury has also been reported on the Yellow Newtown variety grown in Washington, Oregon, Virginia, and New York.

The disorder manifests itself as a browning of more or less elongated areas of flesh extending from the region of the primary vascular bundles. The outer fleshy portion may also show radiating lines of brown tissue, but this condition is usually preceded or accompanied by a more prominent development around the core. The disorder differs from soggy breakdown not only in respect to the radiating lines of tissue but by reason of the fact that the areas affected remain firm, while in soggy breakdown, as might be expected, the flesh becomes soft. Furthermore, the browning most often occurs only in the core region, while in soggy breakdown the browning is found in this area only in the last stages of the disorder. Internal browning is not visible on the surface of the fruit.

The fruits appear to be predisposed to this disorder while on the tree. Low temperature during the growing season favors its development, and fruits from shaded portions, as well as those on trees bearing a light crop, are more susceptible. Fruits of large size and coarse texture are easily affected. Fruits stored at temperatures below 36° F. rapidly develop symptoms.

The most effective control, as indicated, is storage of the fruits at temperatures of 36° F. or above.

Core browning, brown core, or core-flush. Core browning, brown core, or core-flush describe another type of low-temperature discoloration and breakdown.[15, 40] This disorder has been found in the Northeastern fruit-growing regions of the United States, and in Canada, and has developed upon removal from cold storage. The most susceptible varieties are McIntosh, Baldwin, and Rhode Island Greening.

The disorder manifests itself as a light browning of the pith or core region of the fruit as far out as the vascular bundles. There is no sharp line of demarcation between injured and uninjured areas as in brown heart with which it is not to be confused. Furthermore the flesh or cortex is not affected. Although only a small portion of the fruit may become discolored in storage, the area affected increases rapidly when the fruits are removed to a higher temperature.

The following related facts concerning its occurrence and control are important.[15, 40]

1. Immature fruits tend to be more susceptible.
2. Fruits of large size and poor color seem more susceptible.
3. Fruits stored immediately at a low temperature (30° to 32° F.) are more severely affected than those stored at higher temperatures. At 36° F. little or no core-flush develops as a rule. The disorder has been reported as negligible with McIntosh so long as fruits are not stored at 30° to 32° F. until 5 days after picking. It is not found when fruits are stored in common or air-cooled storage. Storage of affected varieties at 36° F. seems preferable in some respects, particularly with McIntosh.

Disorders Associated with Accumulation or Effect of Gases on Fruits

Scald. Scald, a rather serious and common disorder of apple and pear fruits, occurs in storage and in transportation.[8] Except in severe cases, it is superficial, affecting the skin primarily on the side showing the greatest intensity of green ground color. The fruits develop conditions precursive to scald when in cold storage, and the superficial browning occurs almost immediately when the fruits are brought into a warmer air.

The fairly susceptible varieties are: Arkansas, Baldwin, Ben Davis, Grimes Golden, Northern Spy, Rhode Island Greening, Rome Beauty, Stayman Winesap, Wagener, Yellow Newtown, and York Imperial. On the other hand, Delicious, Jonathan, McIntosh, Wealthy, and Winesap are usually quite resistant. Cortland is rather erratic in regard to the disorder.

In mild cases the disorder appears to result in injury to the skin but when severe, the flesh directly beneath also becomes discolored and breaks down.

Facts concerning the occurrence and control of the disorder are as follows:[8, 41]

1. Fruits picked before the proper stage of maturity are more

susceptible. Since the increase of yellow ground color is accompanied by a decrease in the severity of the disorder, the picking of susceptible varieties should be delayed until the ground color has changed from a grass-green to a greenish-yellow.

2. Less scald occurs on fruits stored in air-cooled storage than in refrigerated storage at a temperature of 30° to 36° F.

3. Less scald develops on fruits stored where there is some ventilation, whether in air-cooled or refrigerated storage.[8] Packages and containers should permit as much aeration or ventilation as is practicable under the circumstances.

4. Soil management practices, such as heavy irrigation, which tend to delay the change in ground color from grass-green to yellow, increase the development of scald.[8, 15]

5. Temperatures of 36° F. may result in as much scald as lower temperatures, if other conditions favor its development.

6. Following removal from storage the discoloration develops more quickly at high than at low temperatures.

7. Shredded oiled paper (not waxed) containing at least 15 per cent by weight of an odorless, tasteless mineral oil (18 per cent or more is preferable) should be well distributed in the containers so that each fruit touches the paper at some point. One-half pound should be used for each bushel. This is not a guarantee of complete scald control nor is it equally effective with all varieties, but at least it delays the disorder. The fruits should be packed with the paper as soon as possible after picking since delay may spoil the effect, particularly if the fruits are not well aerated in the meantime.[7]

The cause of scald seems to be the accumulation within the tissues of gases produced by the fruits. Present evidence indicates that the volatile substances responsible for scald are produced for the most part during the preclimacteric phase and possibly also during the climacteric rise in respiratory activity.[25] This is interesting since conditions during the first 6 weeks definitely affect the severity of scald. Thus scald is predetermined by changes in the tissue which may occur a considerable time before injury is apparent. This fact makes it imperative that the fruit be surrounded by the oiled wrappers during this critical period shortly after the fruits are placed in storage.

Pear scald. Two types of pear scald presumably affect this fruit; namely, common scald and Anjou scald.

In the Northwest it is the consensus of opinion that Anjou scald should be differentiated from common pear scald since the differences between them are so distinct.

Anjou scald. Anjou scald results in a brownish or dark discoloration of the skin while the flesh is not involved. The dessert quality of the fruit is not impaired and the disorder is not accompanied by a disagreeable odor as in common scald. It is similar to the apple in that it is controlled by oiled paper.[41]

Common pear scald. Common pear scald results in sloughing off of the skin and the emission of a disagreeable odor. On Bartlett, Doyenne du Comice, and Beurré Bosc the skin is heavily scalded and the flesh disintegrates with accompanying core breakdown. This is associated with the accumulation of acetaldehyde in the tissues.

Common scald will develop on Bartlett pears after 30 to 35 days at 45° F. or 70 to 80 days at 36° F., but does not develop at all when this variety is stored at 31° F.[41] With other varieties the disorder does not usually develop at 32° F., until near the end of the storage period. The disorder cannot be controlled by oiled paper.

Lenticel spotting. Recently a spotting of lenticels induced by the presence of ripe fruits of other varieties as well as by the presence of ethylene was reported by Kidd and West.[26] Considerable difference exists in the susceptibility of varieties to this spotting as well as in the capacity of certain varieties to induce the injury. The spots vary in size from $\frac{1}{16}$ inch or less in diameter up to $\frac{1}{4}$ inch or more and may become confluent, forming odd-shaped patterns. They are usually roundish, and rather closely resemble Jonathan spot although the lenticel spots may be irregular in shape. They may develop when the fruits are stored in air at 40° F. in a confined chamber with ripe fruits of other varieties. Fruits in air when well ventilated or in a modified atmosphere storage showed practically no injury.

Physiological Disorders Associated with Starch-Sugar Changes within the Fruits

Bitter pit or stippen. Bitter pit or stippen, common to certain apple varieties, is a physiological disorder of which the cause and control are still unknown. It occurs in the various apple-growing regions of the world and frequently causes heavy loss.[41]

The disorder is first recognized by the presence of sunken, round or angular spots which appear on the surface of the fruit. These are the result of small portions of the flesh having become brown, spongy, and more or less desiccated.[44] In advanced stages the portions affected may become bitter in taste. The spots tend to occur on the apical portion of the fruit and never develop within the core line. The condition resulting in this disease occurs before picking, but it develops chiefly after removal from the tree.[41]

Varieties differ greatly in their susceptibility. Among the most susceptible are Baldwin, Cox's Orange Pippin, Gravenstein, Grimes Golden, Northern Spy, Rhode Island Greening, Tompkin's King, and Wolf River.

Certain facts are known concerning the occurrence and prevalence of the disorder.[9, 41]

1. Fruits on young trees bearing their first crop or a light crop are particularly susceptible.
2. Oversized fruits whether induced by heavy pruning or heavy thinning are especially susceptible.
3. Nitrogen-carrying fertilizers applied in excessive amounts to trees carrying light to moderate crops tend to increase the amount of bitter pit.
4. Fruits terminally located in the cluster usually show more bitter pit than the laterally located fruits.
5. Fruits picked prematurely tend to show greater injury than those more mature when removed from the trees, other conditions being favorable. Bitter pit developed in storage decreased with the increased maturity of fruits when picked.
6. Delayed storage increases the amount of bitter pit.
7. Cold storage has been found to retard the rate of development, yet the disorder will be apparent as soon as the fruit is removed.

Despite the fact that no control is known, facts presented concerning the prevalence of this disorder indicate the hazard of producing large fruits, of excessive pruning, heavy fertilizing and thinning, as well as of premature picking.

Water core. Water core is a disorder occurring in practically all apple-growing regions. It is more prevalent in a semiarid climate where the temperatures are high and the sunlight of considerable intensity during the latter part of the growing season.[10, 18, 41] In Australia it occurs frequently after heat waves on apple trees with light crops and situated on sites exposed to hot winds and long hours of intense sunlight. With cooler weather, water core if not too advanced, may to some extent disappear. It is questionable whether the tissues affected following severe injury ever really return to normal, and it is believed their storage life is thus somewhat shortened.

Apple varieties differ considerably in susceptibility: among those most commonly affected are Arkansas, Delicious, King David, Jonathan, Rambo, Rome Beauty, Stayman Winesap, Tompkins King, Winesap, and Winter Banana. In Arkansas, Winesap, and Yellow Newtown, water core may disappear, but in Delicious, Jonathan, Rome Beauty, and Stayman Winesap, it is more frequently followed by breakdown.[41]

The disorder is characterized by a hard, glassy, water-soaked region in the flesh.[10, 41] Although the affected areas are commonly found in the core region or adjacent to the primary vascular bundles, any portion of the fruit may gradually become affected. In the early stages the disorder is not visible on the surface but eventually it is noticeable, usually on the side exposed to the sunlight. The water content of the affected areas may be 20 per cent higher than in adjacent portions thus resulting in an increase in weight proportional to the amount affected.[18] The affected areas are also more firm and rigid.

The most important facts concerning occurrence and prevalence of the disorder are as follows: [10, 18, 22, 41]

1. Fruits on young trees bearing their first or a light crop are more severely affected, since a high ratio of leaves to fruits is contributory.
2. Large fruits such as those produced by excessive pruning or thinning are more susceptible. Small fruits tend to make a better recovery than large.
3. Fruits near the tops of trees and in the less-shaded positions are more severely affected. The injury is frequently associated with sunburn.
4. The amount tends to increase with high air temperature as the fruits approach maturity.
5. Irrigation or heavy rains near the end of the season do not appear to be contributory.
6. Ringing or girdling increases the amount of water core.
7. The amount increases with maturity, becoming quite extensive in overmature fruits.

8. Sudden exposure of fruits to sunlight increases water core.
9. Increased leaf area per apple results in a greater amount of water core.

The exact cause of the disorder is unknown. It is apparently associated, as is bitter pit, with a nonuniform conversion of starch to sugar.[18] In the case of bitter pit the disturbance is correlated with removal of water from the tissues, due to the failure of the starch in the cells to turn to sugar; in water core the disturbance is associated with water entering the cells due to the fact that the starch to sugar change has occurred. In the latter case the cells adjacent to the affected portion still contain starch and have a lower osmotic concentration. In some manner enzymatic activity is increased by high air temperatures which may raise the temperature of the flesh 25° to 30° F. above that of shaded fruits. Increased osmotic concentration of the cell sap of the water-cored tissues accompanied by an increase in concentration of sugar apparently establishes localized gradients of water movement until extreme turgor is established.[18]

There is no known control but several precautions will greatly reduce the amount of water core. The fruits should be harvested before they are too mature. Occasionally the incidence of small, water-soaked spots in the flesh or core region near the vascular bundles will indicate the necessity of immediate removal. In McIntosh and Wagener water core disappeared during 3 months' storage at 32° F. Pruning should not result in undue exposure of the fruits to sunlight, and thinning should not be excessive.

MISCELLANEOUS DISORDERS

Jonathan spot. This disorder is known in all apple-growing regions of the world and annually causes considerable loss by discoloring the fruit.[41] It is superficial in nature, first affecting the color-bearing cells of the skin and later the underlying cells in the flesh.

The spots first appear singly as brown, more-or-less circular areas $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter on the surface of the fruit. At first they are only slightly sunken. In later stages they recede farther and often become confluent. Although the fruits may have no trace of the disorder when placed in storage, they may come out very seriously affected.

In addition to Jonathan, other varieties may be affected, including Arkansas Black, Esopus, Gravenstein, Grimes Golden, King David, Ortley, Twenty Ounce, Wealthy, Wolf River, and Yellow Newtown.

Certain facts are known concerning the occurrence and prevalence of the disorder.[36, 41]

1. The disorder is more severe on overripe than underripe fruits.
2. Oversized fruits (usually more mature at a given time) are affected more than small- or medium-sized fruits.
3. The disorder develops more rapidly and extensively in air-cooled storages where the temperatures are relatively higher than in cold storage.
4. Although the spots are infrequently found on mature fruits at harvest, they become more prevalent thereafter, in cases where the fruits are subject to a relatively high temperature, high humidity, and poor ventilation.[36]
5. Jonathan fruits show more severe injury as storage progresses.

The cause of the disorder and a dependable control are unknown. In general, the following provisions have been suggested for keeping the injury at a minimum:

1. The fruits should be picked before they are overmature.
2. They should be stored promptly at the coldest temperature suitable for the variety.
3. Upon removal from storage, they should be kept as cool as possible before being sold. In general they should be used at once.

FRUIT CRACKING

Fruit cracking frequently occurs in several fruits, including apple [46] and the sweet cherry.[49] In some seasons, and with susceptible varieties, losses may destroy the greater proportion of the crop. Cracking is associated with an excessive acceleration of fruit enlargement as a result of a marked increase in the water content of the tissues involved.

Cracking in the cherry. Sweet cherry fruits are much more susceptible to cracking than the sour cherry. In a conducive season Bing is the most susceptible variety, followed by Napoleon and Lambert. Regional and seasonal factors will naturally modify the disorder. Republican, Eagle, and Yellow Spanish are resistant types.

The outstanding circumstances related to cracking are: [49]

1. Absorption of moisture through the skin of the fruit either as a result of rainfall or immersion in water.
2. Environmental conditions favoring low transpiration at a time when the moisture content of the fruit is already high.

3. Increasing maturity. When the sugar content of the fruit attains a certain level (15 to 16 per cent in Lambert) the fruits become more susceptible, if environmental conditions are conducive.
4. Cracking is not positively correlated with soil moisture unless environmental conditions favor the maintenance of excessive fruit turgor.
5. When other conditions are contributory, high air temperature will induce cracking.
6. Large-sized fruits are more susceptible.
7. Fruits tend to crack if picked when their turgor is high. For example, cracking is more severe if the fruits are picked during the early morning hours than during the afternoon, when they are usually less turgid.

The fruits differ in their susceptibility to cracking because of difference in the rate of absorption of water in conjunction with unequal capacities for expansion of peripheral tissues. Varieties with a rapid rate of absorption (due to a very permeable skin) and a small capacity for expansion crack readily, while those with slow rate of absorption together with a pronounced capacity for expansion are slightly susceptible or immune to cracking. Differences in this respect not only occur between varieties but between fruits of the same variety.[1]

At present there is no dependable procedure which will prevent cracking. Avoidance of varieties which are most susceptible, as Bing, tends to reduce losses. Fruits should be picked as soon as they attain a reasonable degree of maturity, since rains at full maturity tend to be very destructive. Spray applications containing lime, such as dilute Bordeaux mixture, applied just previous to harvest, are reported to be of some value. Recently, Verner has shown that calcium is the protective agent which reduces cracking.[48] In view of the undesirable residue on the fruit, the prevention of cracking by spray applications is still in the experimental stage.

Cracking in the apple. Although the most serious cracking in the apple is concerned with Stayman Winesap, other varieties may occasionally exhibit an appreciable amount. Wealthy may even crack badly, while a type of lenticel cracking involving many small cracks is common in York Imperial. Jonathan and even Winesap sometimes crack sufficiently to affect the salability of the fruit.

The outstanding facts concerning the occurrence of cracking in Stayman Winesap are as follows:[46, 47]

1. It is induced by environmental conditions favoring low transpiration when the water content of the fruit is high.
2. Cracking tends to increase when a period of high humidity follows a period of prolonged water deficit.
3. Cracking will develop on fruits untouched by rainfall, indicating that water absorption through the skin is not, as in the cherry, of primary importance.
4. Cracking is not positively correlated with soil moisture except where the environmental conditions favor low transpiration when the water content of the fruit is already excessive.
5. Susceptibility to cracking begins about two months previous to harvest and increases with advance in the season.
6. Cracking usually is more severe on branches and spurs having sparse foliage.
7. The cracks are usually initiated in areas where slight russeting has developed, either as a result of hypertrophied lenticels, scab lesions, sunburn, frost, or spray injury. Areas previously injured by sun-scald or possessing unusually high overcolor are quite susceptible.[47]
8. Fruits in shaded portions of the tree, having a thinner and probably more flexible skin, show much less injury.

The disorder is believed to be the result of unequal growth or enlargement of the flesh (cortex) and of the epidermal and hypodermal layers.[47] With high turgidity of the flesh the stress apparently becomes too great for the slower-growing surface tissue.

There is no known control. Some growers avoid Stayman Winesap and plant the resistant variety, Turley. Since russeting is conducive to cracking, care should be taken to prevent unnecessary russeting. Caustic spray materials should be avoided.

Pear Black-End

Black-end is a disorder affecting the fruits of European pear varieties (*Pyrus communis*) which have been budded or grafted on understocks of several Oriental pear species, namely *P. ussuriensis*, *P. betulaefolia*, and *P. serotina.*[16] More specifically, Beurré d'Anjou, Bartlett, Beurré Clairgeau, Doyenné du Comice, Easter Beurré, Wilder, and Winter Nelis are affected. Seedlings of Kieffer tend to exhibit this injury and unfortunately some nurseries in the

East have distributed these seedlings for grafting and budding Bartlett and other European varieties. Although the disorder is widely known in California, it has also been observed in the East.

The disorder is manifest in a blackening of the calyx end of the fruit, no injury yet having been observed to the tree. When the fruit is one quarter to one-half grown (Bartlett, approximately 60 days after full bloom) a protrusion develops on the tissue around the calyx with an associated enlargement of the calyx opening. The epidermis over the affected area at first becomes tight and shiny with the calyx lobes turning black. The affected tissue around the calyx then becomes hard, gritty and woody, brownish in color at first, and then black. Eventually the injured area may spread backward away from the calyx region. The discoloration does not extend deeply into the flesh, but the region may eventually crack.

The physiological cause of the disorder is unknown. Unfavorable soil moisture conditions, or shallow rooting are reported to be conducive to its development. The amount of injury varies seasonally, but its relative severity on different trees shows no variation from year to year. The calyx end has been found to be more alkaline in black-end fruits, indicating some association between injury and the hydrogen ion concentration of the fruit.

There is no known control. The disorder can be curtailed by avoiding trees propagated on the Oriental species or Kieffer seedlings. Inarching of Bartlett with seedlings of *Pyrus communis* did not reduce injury unless the roots of the oriental rootstocks were severed from the trunk.

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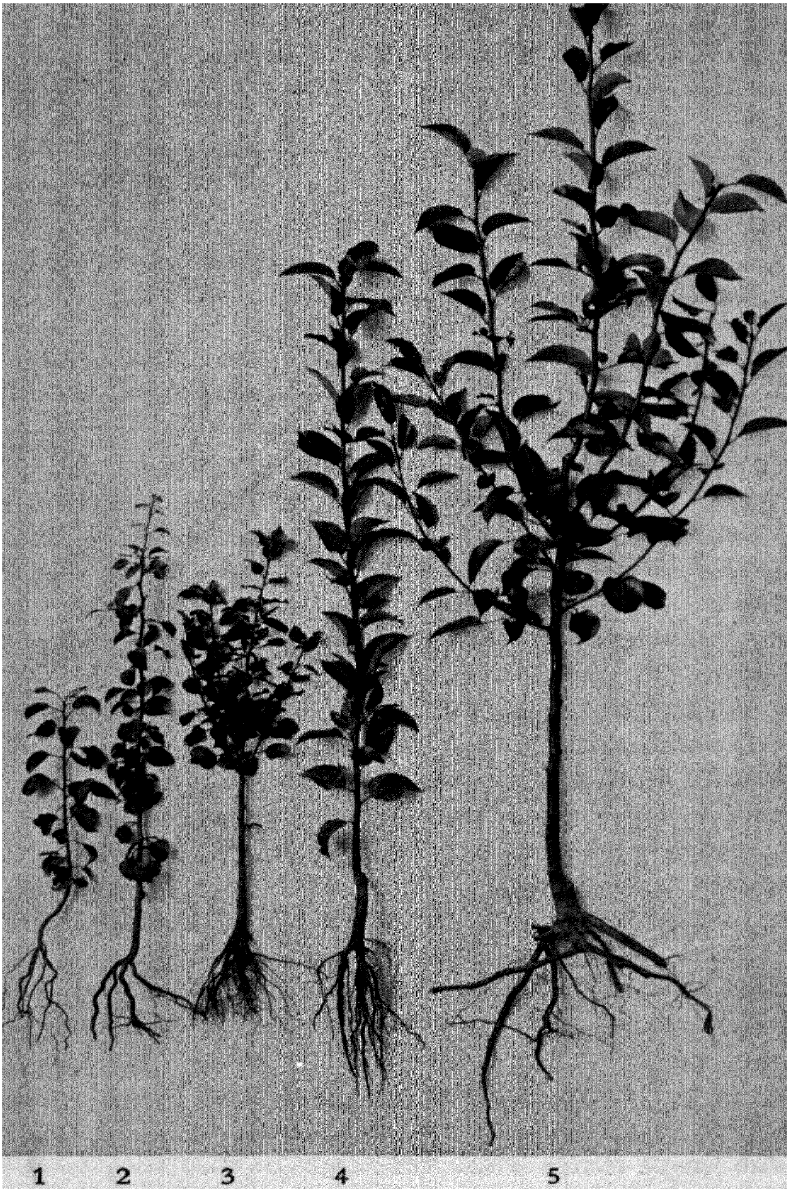
15

PROPAGATION AND STOCKS

The fact that varieties of fruit do not "come true" from seed precludes the use of sexual propagation as a means of developing the fruiting portion of a plant for use in commercial orchards. A modern planting made up entirely of individuals differing from each other in fruit and plant characteristics is unthinkable now, though in early colonial days and in the Indian villages such orchards were fairly common. Fruit varieties are all heterozygous, that is, have been derived from the union of dissimilar gametes. Thus they in turn will produce gametes of dissimilar genetic constitution, and the new individuals produced by this union will differ in one or more respects from their parents. Even in those varieties or species, such as the peach, which produce new individuals by self-fertilization, offspring varying somewhat from the parent will, nevertheless, occur. This situation, which is necessarily an obstacle from the point of view of the multiplication of desirable individuals, is, on the other hand, of paramount importance in giving rise to improved varieties with entirely new characteristics.

In the production of the modern fruit tree, sexual and asexual propagation complement each other. The tree usually consists of at least two portions, joined together by budding or grafting, the scion having been multiplied vegetatively and the stock frequently, though not always, grown from seed. (Fig. 75.) The brambles and usually the grape differ from tree fruits in that they consist of only one portion, the rootstock having been eliminated, due to the readiness with which they may be propagated from stem or root portions.

Definition of terms. Before considering various phases of the subject the terms commonly used should be understood. The student should familiarize himself not only with older terminology, but



(Courtesy H. B. Tukey. New York Agr. Exp. Station, Geneva.)

FIG. 75. The development of a young apple tree. From left to right: 1, seedling rootstock just before digging in seedling nursery (Fall of 1931); 2, lining-out stock (Spring of 1932) soon after planting; 3, at time of budding, bud in place (Summer of 1932); 4, yearling tree (Fall of 1933); 5, 2-year-old tree (Fall of 1934).

also with those expressions which have developed along with recent trends in the field of rootstocks and propagation.[70]

The term *stock* has been given to the plant or plant part upon which the scion variety is budded or grafted. The *scion* (also cion) is the portion of the plant which is topworked on the stock. If the scion is only a bud, with a portion of the bark and wood of the shoot attached, the operation of inserting the new variety is termed *budding*. Later on the scion in turn may be topworked (*double working*) by budding or grafting to still another variety which is called the *scion variety*, in which case the erstwhile scion thereby becomes the *intermediate stock*. For example, trees of the Virginia Crab variety as found in the commercial orchard are usually a combination of Virginia Crab scions budded or grafted on French Crab stock. When such a tree is topworked to another variety such as Jonathan the latter is known as the scion variety and Virginia Crab as the intermediate stock. It has been suggested that this relationship might be designated as follows: Jonathan/Virginia Crab/French Crab.[70] Despite the fact that the tree may be made up of two or more components the tree is usually named and labelled after the scion variety.

The term *rootstock* has been commonly used to denote the portion of the tree making up the root of the grafted or budded plant. The term, *understock*, is sometimes considered preferable since rootstock is frequently used specifically by botanists to denote "a stem of root-like appearance on or under ground, from which rootlets are sent off." Thus the term becomes synonymous with rhizome. However, since the term rootstock has been in use for so long it will probably continue. The understock may consist only of root, or it may be comprised both of root and a portion of the stem which is usually rather short, extending only to the point at which the scion was inserted.

Recently the word *clone* has reappeared in horticultural usage, largely because of the modern trend toward the vegetative propagation of selected stocks. Bailey has defined a clone as a "variety, or group of varieties propagated only by asexual or vegetative means."[9] Thus all the individuals of the variety Baldwin, as well as all horticultural varieties of apple, peach, pear, strawberry, and other fruits comprise a clone. Furthermore, if a seedling is propagated vegetatively for stock purposes, the various individuals so obtained constitute a clone. The East Malling types of understocks are clones. Tukey has suggested that in considering fruit stocks, a clear-cut distinction should be drawn between *seedling* stocks (obtained from seeds) and *clonal* stocks derived from the asexual multiplication of individuals (seedlings, for example).[70]

SEXUAL PROPAGATION

The rootstocks or understocks upon which fruit trees are budded or grafted are usually obtained by means of sexual propagation. Among the more important of these are the French Crab and peach seedlings commonly used for the apple and peach respectively. In addition the breeding of new varieties, by crossing or selfing those already established, constitutes a secondary application of sexual propagation.

After-ripening. As a rule seeds of hardy fruit plants will not germinate or sprout directly upon removal from the fruit after harvest. At this time the embryo has not yet undergone sufficient development, and certain chemical changes which are the forerunner of germination have not taken place. The period during which these changes occur, and during which the seed fails to germinate even under conditions otherwise favorable, is called *after-ripening.* In the peach, embryos removed from fruits and grown on a culture medium in the laboratory may germinate and show some development, but vigorous seedlings will not develop unless after-ripening has occurred. The length of this period depends not only upon the environmental conditions to which the seeds have been subjected but also upon the kind and variety of fruit.

The idea was prevalent for many years that environmental conditions favoring after-ripening involved alternate freezing and thawing temperatures. It was formerly the universal practice to stratify seeds of the various fruits in the fall, a procedure which involved placing them in layers of sand in an outside bed where they might be exposed to normal temperature and moisture conditions of the winter season.

However, as a result of considerable experimentation,[12, 26, 33, 68] it is now known that the most favorable temperature for after-ripening the seeds of hardy fruits ranges from 38° to 41° F., and that the lower temperatures, between 33° to 38° F., are more favorable than those above 41° F. Above 50° F. no after-ripening will take place. Furthermore, a dry atmosphere, even at the correct temperature, prohibits the process, although drying before the period of after-ripening does not appear to reduce germination.[88] On the other hand it is essential to keep the seed moist *following* after-ripening, and up to the period of planting, since germination may be greatly reduced or prevented if the seeds are dried for two or more days at this time. Furthermore, they will tend to germinate at the after-ripening temperature, provided the pericarp or stone does not interfere. Consequently, the seed must be kept not only moist but at a reduced temperature in order to prevent germination until the proper time.

Since it is now known that freezing is unnecessary, and in fact injurious, an increasing amount of seed is annually after-ripened under controlled conditions. As a matter of fact, after-ripening out of doors during the winter may proceed very slowly if the temperatures are too low. The seed may be stratified in moist sand in an ice house, in a cool cellar, or in the ice compartment of a refrigerator—in fact, wherever proper temperature and moisture conditions prevail. Large nurseries which raise apple seedlings now soak the seeds for several days in cold water and then place them between cakes of ice in storage where the temperature will range somewhat above 32° F.

The length of the after-ripening period varies considerably in the different fruits. Furthermore, the stated length of the periods has gradually been reduced as a result of increased experimentation and a more definite knowledge of the conditions favoring after-ripening. For example, the peach was formerly said to require as much as 105 days, but recently the period has been decreased to 30 days. The requirement for the different fruits varies as follows:

Apple	28 to 42 days
Pear	45 "
Peach	30 to 84 "
Cherry	
Mazzard	100 "
Mahaleb	88 "
Plum	84 to 112 "
P. americana	150 "

ASEXUAL PROPAGATION

Multiplication of the individuals of a clone is accomplished asexually in one of two ways. In the first place it may involve the formation of roots upon a portion of a stem or leaf or, conversely, the formation of shoots upon a root. Portions of the plant to be propagated may be either attached to or detached from the parent plant.

The second alternative involves the union of a scion with an understock which may have been propagated asexually, as above, or from seed. The first type of propagation includes such methods as layering and the rooting of cuttings; the latter is accomplished by means of budding and grafting.

The various fruits are not propagated with equal success by all methods. In view of the difficulty with which stem cuttings of commercial varieties of tree fruits are propagated, recourse to budding and grafting is the usual procedure, certain methods having become standard for given plants. The methods for the various fruit plants are grouped as follows:

- Layering
  - Tip-layering
  - Trench-layering
  - Mound- or stool-layering
- Rootings of cuttings
  - Stem cuttings
    - Hard-wood
    - Soft-wood
  - Leaf-bud cuttings
- Production of shoots and roots on cuttings
  - Root cuttings
- Budding
- Grafting

Layering

Layering involves the development of roots upon stems which are still attached to the parent plant. A *layer* is an attached shoot partially covered with soil to encourage rooting, after which it is severed from the parent stem.

Tip-layering. This is the simplest and most common of the layering methods. The parent stem is merely bent or arched into the soil and secured by a light covering of earth. After rooting, the young plant is severed, in the fall or spring, and planted in the nursery or fruit plantation. Grapes, particularly the Muscadine (*Vitis rotundifolia*), may be propagated in this way while the black raspberry reproduces itself naturally by this method. The trailing blackberry, loganberry, and dewberry are commonly propagated by tip-layering. Occasionally the long canes bend to the ground, push into the soil, and take root naturally.

Trench-layering. The stems of the variety to be propagated are bent over into a shallow trench (2 or 3 inches deep) and the tip and internodes are usually pegged to hold the stem in place. The stem is then covered with a very thin layer of soil which is gradually increased as the new shoots develop. Very little soil must be added at first or many of the buds will fail to unfold. On the other hand, if the bases of the new shoots are exposed to light, they will become woody, which inhibits rooting. The process of adding soil at intervals is repeated until the layered stems are covered to a depth of 6 inches. In late fall or early spring the soil is drawn away and each rooted stem is removed from the parent plant.[78]

Clonal understocks of the pear, cherry, and plum (St. Julien and Myrobalan) and the more vigorous varieties of quince are usually propagated in this manner in England. It is more expensive than the present use of seedling stocks and will come into general use in this country only when certain selected stocks are shown to be markedly superior. In New York trench-layering was found to be more successful with the stronger rather than the weaker-growing Malling types, particularly Types XII, XIII, and XVI.

Mound- or stool-layering. A plant which has been cut back to produce a large number of shoots suitable for layering is called a "stool" by nurserymen. Before growth starts in the spring the aboveground stems are cut back so that the new shoots will come up as close to the ground as possible. Then as they develop they are covered with soil or "mounded," one after the other, to a final height of 6 or 8 inches. Roots will then develop at the base of the shoots at the point at which they are attached to the parent plant. The following fall the earth mound is removed and the new individuals separated.

Mound-layering is the principal means of propagating the currant, gooseberry, some quince types, and certain clonal apple understocks such as the Malling types. At Geneva, New York, the Malling rootstocks, particularly the weaker types, were found to produce sufficient plants by means of mound-layering to make their propagation commercially practicable.

Rooting of Cuttings

Stem cuttings. Certain plants may be readily propagated by inducing root formation on portions of the stem previously removed from the parent plant. Either the soft, succulent portions of the stem (soft-wood cuttings) or mature wood (hard-wood cuttings) may be utilized with certain plants, while only one method is applicable to others.

Soft-wood cuttings. Attempts to propagate the apple from soft-wood cuttings invariably fail.[8, 62, 71] On the other hand, the Mahaleb cherry roots well, and similar results were obtained at Geneva, New York, with soft-wood cuttings of the Italian Prune, the Lyons and Mazzard cherries, and the Seckel pear. As indicated, however, these fruits are still generally propagated by budding and grafting.

Recently indoleacetic acid, indolebutyric acid, and compounds of a similar nature have been used in attempts to stimulate root formation in soft-wood cuttings.[13, 54] In England the Myrobalan plum and the Malling "free" or vigorous pear stocks showed increased root formation as a result of treatments with α-naphthalene acetic and indolebutyric acids (at dilutions of 20 to 40 parts per million for 12 to 24 hours). Malling Type I apple cuttings rooted well when taken both in active growth and when the terminal bud had formed, whereas Malling Type II failed to root. Cuttings of plum varieties varied considerably in response to the treatment.[13]

At Geneva a small percentage of Montmorency cherry cuttings rooted in response to indolebutyric acid, and in Iowa sprouts of Virginia Crab were induced to form roots, but as yet these substances have not proved practicable in producing own-rooted trees of the plum, pear, cherry, or apple. The success of the treatment depends upon several factors of which concentration of the chemical, length of treatment, and physiological condition of the cuttings are very important.[13]

Hard-wood cuttings. Hard-wood cuttings of the gooseberry, currant, Marianna plum, and the Myrobalan plum, may be readily rooted. With the grape this is the method most commonly employed. Auchter [8] has presented a comprehensive review, to which the student is referred, of the various attempts to propagate the apple both by hard- and soft-wood cuttings. Very unsatisfactory results have been secured in attempting to obtain roots by this method with commercial varieties of the apple, even following the application of indoleacetic, indolebutyric, and α-naphthaleneacetic acids. On the other hand, at Geneva the Malling stocks IX and I rooted quite well, while Types XII and XIII rooted poorly, even following chemical treatment.

Recently Gardner [21] has reported marked success with rooting stem cuttings of apple varieties. The growing point of the stem is etiolated in the spring just before bud break. When the stem has elongated 2 to 3 inches, the shoots are exposed to the light and taped at their bases. They are allowed to continue growth for some time and are then removed in late August to the nursery where rooting takes place. The varieties responding best to such treatment were Opalescent, Northern Spy, McIntosh, Baldwin, Fameuse, and Northwestern Greening. Wealthy, Yellow Transparent, Golden Delicious, and Willow Twig showed the least effect.

In order to induce rooting in stem portions of apple varieties, what has been called the long scion-nurse root method has been employed. A long scion of the variety to be rooted is grafted to a short portion of a seedling root. Both are then deeply planted in a well-aerated soil for the purpose of encouraging root development on the scion above the nurse root. In general, this procedure, together with various modifications, has given only mediocre results, depending in part upon the variety, soil, and other factors.[47]

One of the more successful of these modifications involves the use of wire-wrapped bench grafts. This consists of ordinary scion and root piece grafts, wrapped snugly with No. 18 copper wire 3 or 4 times just above the union.[22] Grafts made during the late winter or early spring will, when planted under favorable soil conditions, show scion rooting by fall. Most apple varieties have been found to root fairly readily by this treatment. In Iowa, Virginia Crab, Hibernal, and Dudley responded surprisingly well to this treatment. Gardner and Marth recently reported[24] that of a number of varieties the percentage to scion root by the end of 2 seasons in the nursery varied from 100 per cent for Perkins to 42 per cent for King David. All varieties rooted better than 80 per cent with the exception of Nero, Jonathan, Oldenburg, Wealthy, Golden Delicious, Williams, and King David, which varieties are considered "relatively poor rooters." Some varieties produced fibrous and others hairy roots, while several others are distinctly coarse rooted and lacking in fibre, the roots being few in number, long and relatively unbranched. These varieties, believed to be undesirable because so much of the root system is lost in digging, are: Delicious, Lodi, Stark, Stayman Winesap, Summer Rambo, and York. Arkansas (Mammoth Black Twig), Northwestern Greening, and McIntosh also produce undesirable root systems while, on the other hand, scion-rooted trees of Red Astrachan, Fameuse, Hibernal, Crimson Beauty, and Rhode Island Greening look promising. By means of this procedure sufficient trees have been obtained for experimental plantings. Maney,[47] for example, found that Virginia Crab, Hibernal, and Dudley responded surprisingly well to this treatment, but the method is not considered commercially practical as yet.

Another modification consists of reversing the root, thus grafting the scion into the apical instead of the basal end. By this system the stock is in an inverted position and the scion in the normal position when planted. The restriction stimulates root development just above the union, while the stock develops but little. This method has been reported to give satisfactory results with crabapples, ordinary standard apple varieties, pear, plum, and sand cherry.[42, 45]

Leaf-bud cuttings. By this method, cuttings of *Rubus* are made consisting of a leaf together with the bud in the axil of the leaf, and a small attached shield of bark and wood from the cane.[3, 61, 65] In Iowa the procedure was reported to be very successful when cuttings were taken in late July and placed in sand or sand and peat in heated frames until the roots were well developed. Angelo notes that leaves from the central portion of the cane and having a substantial "heel" were preferable.[63]

The method has been very satisfactory with the black raspberry and gooseberry and reasonably successful with the blackberry. Other forms of *Rubus* which rooted in a comparatively short period from leaf-bud cuttings are *Rubus armeniaca*, *R. ellipticus*, *R. fraxinifolia*, *R. glaucus*, *R. parviflora*, and *R. leucodermis*, the Brainerd blackberry, and the Van Fleet raspberry.[65] On the other hand, the red raspberry varieties Chief and Latham failed to root satisfactorily.

Production of Shoots and Roots on Cuttings

Root cuttings. Propagation of fruit plants by root cuttings is relatively successful in the cherry, certain plum varieties, red raspberry, and the upright blackberry.[78] This method with tree fruits is likely to be commercially impracticable, however, so long as other means are successful and less difficult. In the first place, the cuttings must be taken from trees of standard varieties which are on their own roots; namely, scion-rooted. The other difficulty arises from the fact that although shoots develop from such cuttings usually further root growth is definitely limited.[74]

Stoutemyer, Maney, and Pickett [63] in Iowa report surprising success in propagating Virginia Crab from root cuttings. A tightly closed propagating frame in which the humidity was kept extremely high and temperature at 75° F. was set up in the greenhouse. Roots taken in November were cut in lengths of 6 inches and laid horizontally on the surface of moist sand where they were fully exposed to the humid air. Vigorous shoots several inches long developed within 1 to 2 months at which time the cuttings were divided, leaving a piece of root 1 to 2 inches long attached to each shoot. The divided root cuttings were then placed in sand in an open propagating bed in the greenhouse, where roots developed abundantly.

Available evidence indicates that the size and diameter of the root cuttings, temperature and humidity of the propagating frame, and the position of the proximal end of the cutting when placed in the soil are factors which, in addition to the variety, determine the success of this method.

Budding and Grafting

The practice of developing a fruit tree from two individuals, the rootstock and the scion, by means of budding and grafting is centuries old. Chang notes that in China as early as 500 A.D. the Oriental pear, *Pyrus serotina*, was "best suited" to propagation on "Tu Li," a variety of *P. phaecocarpa*, Rehd.[15] It was also reported at that time that the Japanese plum (*Prunus Salicina*) could be successfully grafted on the peach, while the reciprocal combination failed to grow.

Incompatibility. Until recent years information regarding the compatibility of various combinations has been largely obtained by trial and error and as a result was often fragmentary and misleading. With experience and observation it was gradually concluded that a union was not fully compatibile except between varieties of the same species or between closely related species of the same genus. However, even this observation is too general since *incompatibility* between varieties within a species may be more pronounced than between species, thus indicating the complexity of the problem. Chang [15] points out that older conceptions regarding botanical relationships as a guide to incompatibility must be modified, since plants of different species and even of different genera are commonly and successfully joined in a graft or bud union. On the other hand within the same species, marked differences in compatibility may occur.[2] Hatton, for example, has shown that different quince selections belonging to the species *Cydonia* *oblonga* (*vulgaris*) Lindl. are not all equally compatible with pears. Again some plum varieties of *Prunus domestica* show a lesser degree of compatibility with common plum stock (*P. domestica*) than with a cherry-plum selection, Myrobalan A (*P. cerasifera*).

The nature of incompatibility has received relatively little study, but several interesting contributions have been recently made. From these studies it is evident that incompatibility is not always absolute; in other words it is not a matter of the *complete* failure of stock and scion to grow contiguously. Rather it is a question of degree and must be considered over a period of time. All incompatible combinations tended to exhibit one or more of the following manifestations:[2, 15]

1. Low percentage of bud or scion "take."
2. Premature autumn leaf coloration.
3. Premature flower-bud formation.
4. Early defoliation,—first from the tip rather than from the base.
5. Dying back of young shoots.
6. Mechanically weaker union.

The two outstanding indications of incompatibility are:

1. All incompatible combinations show a mechanically weak union.
2. The union when broken is relatively smooth.

Incompatible combinations may grow more the first year than compatible unions, but with the second and third year a decline in growth, more or less in proportion to the degree of incompatibility, takes place. A decline in root growth is also proportional; the roots of incompatible combinations are more sparse and shallow and tend to start later in the spring.

From a practical viewpoint, it is evident that a slight incompatibility may tend to suppress vegetative growth, and thus induce prolific bearing. In this connection it is interesting to note that in some compatible combinations bearing is advanced, and certain of the manifestations of incompatibility, such as reduced top growth and a lower $\frac{\text{top}}{\text{root}}$ ratio, are observed. Thus it should not be inferred that such indications are necessarily manifestations of incompatibility. The final index must be the strength of the union and the smoothness at the point of fracture. For example certain of the Malling type stocks are dwarfing, yet the union between stock and scion is unquestionably strong.

There is still no satisfactory method of determining immediately whether or not a specific combination is compatible. Experience shows that symptoms of incompatibility appear earlier and are more pronounced when the tree is grown under adverse environmental conditions. As defined by Argles[7] incompatibility "may be regarded as inherent antagonism, or discordant association between certain stocks and scions, the cause or causes of failure or abnormalities arising out of the nature of the two plants, and the form taken by the failure being governed in greater or less degree by the subsidiary factors of environment and treatment. Thus under external conditions which favor union and growth, failure will tend to be delayed, while under unfavorable conditions of environment and treatment it will tend to be accelerated." It is apparent that a combination of stock and scion may continue to grow for years until finally a heavy crop or a windstorm may result in fracture, thus indicating a relatively weak union.

Specific directions for budding and grafting.[*] Grafting is generally divided into two major divisions: (1) scion grafting and (2) bud grafting or budding. Each of these divisions is again divided into many subdivisions according to the different methods and parts used in making the union.

Since growth takes place in the cambium and other closely associated meristematic cells, it is essential to bring the cambium tissue of both stock and scion into contact with each other, their subsequent growth forming a continuous layer of new wood uniting the parts as one. The cambium is a single layer of cells lying just between the inner bark and the wood; there are usually several layers of cells adjacent to the cambium which have not become differentiated into other tissues, and these cells with the cambium are termed the cambial region. The cambium layer is the tissue of the stem which accounts for diameter increase, and further growth depends on its preservation.

Selection and care of scions. The selection and care of scion wood for grafting are of utmost importance. Twigs that have made growth of from 1 to 2 feet during the preceding season usually furnish the best scion wood. The buds should be plump and mature. The midportion of the 1-year growth furnishes the best scions;

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[*] The specific directions for budding and grafting have been largely taken from the work of Mr. I. P. Lewis, entitled "Grafting and Budding Fruit Trees," Ohio Agricultural Experiment Station Bulletin 510.[46] For the use of this material the writers wish to express their appreciation.

basal and tip portions of most 1-year growth contain underdeveloped and weak buds. Two- or 3-year wood may be used at times under special conditions but is not recommended.

It is essential that scions be kept dormant until set in the stock. Scions may be cut during the winter while dormant, but care should be taken to keep them cool and moist until time for using. They should be wrapped in cloth or paper and buried in the ground below frost level in a well-drained location, or they may be stored in a cool cellar in slightly moistened sand, sawdust, or sphagnum moss. Scions coated with paraffin before storing were superior to those stored without coating and were practically equal to fresh-cut scions, especially for use during March and April, the normal grafting season. If scions stored in sawdust alone are kept moist and cool, they will give good results.

Best results are obtained in coating scions with paraffin wax if they are quickly dipped in wax having a temperature of 170° to 180° F., which is just below the point where the wax becomes smoking hot. The temperature should not be above this point or the hot wax may cause injury, and it should not be below 160° F. or too heavy a coating will be secured and will have a tendency to crack and flake off. This coating of wax remains on the scions after being set and materially aids in the possibility of making a successful graft union with the stock. Caution should be exercised in the use of paraffin in very hot climates. Paraffining particularly of nursery trees has not been successful because of injury on the sunny side.

Time of grafting. Ideally the scions should be cut in the spring just before growth starts, and grafting should follow immediately but only a limited amount of grafting can be accomplished in such a short period. Where scions can be kept dormant in storage, grafting can be successfully done even though the trees have attained considerable growth. The general rule for successful grafting is that scions should be as dormant as, or more dormant than, the stock. By using basal growth from small 2- or 3-year twigs containing latent, dormant buds and by coating the entire scion as well as cut surfaces of the stock with melted wax, successful grafting can be accomplished even as late as July. In fact, using the improved method of waxing, successful grafts have been made in Ohio every month from November to August. However, for practical use, just before and as the buds are starting in the spring is the best time for grafting.

For growing young fruit trees, whip grafting of seedling root stocks may be done during the dormant season in winter, and the grafted stocks stored in moist sawdust or moss in a cool cellar or buried out of doors until time for planting in the spring. These grafts have been found to callous best at 59° F. Topworking of trees by the cleft-graft method is generally done immediately before or just as the growth is starting in the spring. Some other forms of grafting, such as bark grafting and bridge grafting, that involve the loosening of the bark, are most conveniently done a little later in the spring when the bark has begun to slip well.

Topworking. Changing the entire top of a tree to a different variety is called topworking. Mature trees may be topworked, but the older the tree and the larger the branches the more difficult is the task. In selecting limbs for topworking, each tree must be studied as an individual problem and limbs should be selected for grafting with reference to the future framework and form of the tree. Vigorous limbs, well distributed around the tree, and sufficiently wide-spaced on the trunk so that no bad crotches are formed, should be selected. For the future leader, a vigorous, upright branch in the center of the tree should be selected for grafting. A branch leaning slightly toward the prevailing wind is best suited for this purpose. The limbs should be cut off as close to the trunk as necessary in order to obtain a diameter of from 1 to 2 inches on which to graft. Where the main limbs are too large, these may be cut back to vigorous, lateral branches and these smaller laterals cut for grafting. The most successful grafting of older trees is that in which the scions are placed in small wood, preferably not over 2 inches in diameter. This fact has been emphasized by the very extensive experience with topworking older trees in the Northwest. It is impractical to work into wood 3 inches and up without wood rots gaining a foothold, and this more than any other factor has been responsible for failures in topworking older trees.

The majority of the remaining limbs which are not to be grafted, are then removed. Enough are allowed to remain, however, to shade partially the limbs upon which the scions are set, thus protecting them against sun-scald. For this reason, on mature trees it is necessary to extend the time of topworking over 2 or 3 seasons.

During the growing season after the grafts are set, water sprouts will grow in profusion over the limbs and around the grafts. These, for the most part, should be cut out, but a few should be cut back and allowed to remain as they will furnish sufficient shade after the first season so that the majority of the heavier wood of the tree can be removed. After 2 or 3 seasons when the grafts have made sufficient growth to shade the inner portion of the tree, all other growth is removed. The graft growth itself is next thinned out. Where double grafts have grown, one of these is removed and the tree pruned to correct its form.

The four principal methods of grafting used to topwork trees are: cleft grafting, whip grafting, bark grafting, and budding.

Cleft grafting. Cleft grafting is the most common method of topworking. Limbs from 1 to 2 inches in diameter are grafted in this manner. Larger limbs may be grafted by using 2 clefts parallel to each other, one on either side of the center and inserting 4 scions. On both young and old trees the scions are placed in the branches.

Cleft grafting of young trees. When young trees have been planted 2 to 4 years, selected lateral branches are grafted at the desired distance from the trunk. The point of grafting may be 18 to 24 or more inches from the point of union of the lateral with the main axis. If the diameter of the lateral at the point of grafting is an inch or more, the cleft graft will be satisfactory; if less than 1 inch, other methods of topworking are preferable.

In cleft grafting such small laterals, the branches are cut off with a beveled cut and 1 scion inserted. Often on these small-sized limbs the pressure of the stock does not hold the scion securely enough. In this event, the scion should be bound in the cleft tightly by wrapping. Muslin strips impregnated with grafting wax, or waxed tape have been used for this purpose. But since these waxed strips are unpleasant to handle, it has been found that this difficulty can be overcome by the use of paraffin brush wax. The graft may be wrapped with dry narrow strips, and a touch with melted wax will fasten the loose end down. The entire wrapping is then brushed with melted wax, the hot wax soaking into and through the cloth, sealing the graft airtight. This same method may be used wherever binding or wrapping is necessary in any grafting operation.

Cleft grafting of older trees. In making a cleft graft in older wood the limb to be grafted should be sawed off with a fine-toothed saw. A point should be selected for this cutting where the wood is smooth and straight grained for at least 4 inches below the point where the limb is cut off. A special tool known as a "grafting tool" may be used to advantage in making the cleft and in holding it open to receive the scion. In splitting the stubs of side branches, the cleft should be made in a horizontal direction; and, on vertical stubs in the top of the tree, the split is made in a direction allowing one scion at least to face the prevailing wind. On limbs that are cut to a bevel and only one scion set, the scion should always be placed on the upper or outer edge at the highest point of the bevel. After the cleft is made the grafting tool is removed, turned over, and the wedge on the outer end hammered into the cleft at the center of the stub. This opens up the cleft so that the scion can be easily inserted without tearing the bark. (Fig. 76.)

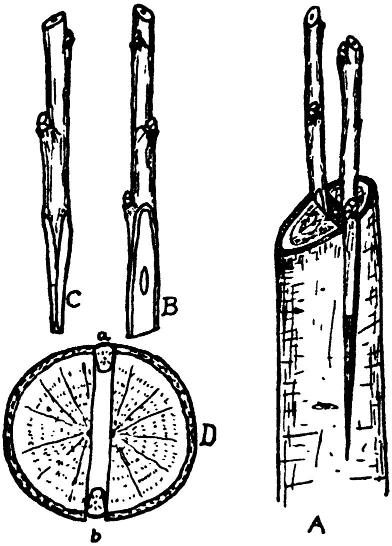

FIG. 76. The cleft graft. A, cleft graft completed ready for waxing; B, side view showing bevel of scion; C, back view showing wedge-shaped bevel of scion; D, cross section of cleft graft: a, incorrect method of setting scion, no cambium contact; b, scion correctly set to insure cambium contact.

Scions are usually cut from 3 to 5 buds long for topworking. The scion is cut off directly above the top bud. Beginning at the base of the lowest bud, the lower end of the scion is cut slightly thicker on the bud side in a wedge shape with uniform, even sides. Usually this wedge should not be over 1½ to 2 inches in length and should be blunt on the lower and front end, rather than drawn to a fine, long point. The idea is to cut the scion as nearly to fit the cleft in the stock as possible.

The prepared scions, one on either side, are then inserted in the cleft with the wide edge of the scion outward, so that the stock will clamp the scion most firmly in the region of the cambium. They are then slipped downward into the cleft until the lower bud is close to the cut surface of the stock. An effort must be made to make the line of the cambium layer of the scion as nearly continuous as possible with that of the stock. Since the bark of the stock is thicker than that of the scion, the scion will always be a little towards the center rather than flush with the outside bark of the stock. Sometimes the scion is tilted very slightly to the outside, as this insures a contact of the cambium layers at some point, although this is usually unnecessary. All cut surfaces of both stock and scion should be carefully covered with wax to keep the parts from drying out before union has taken place. Care should be taken that the split on the sides and top of the stock is filled and covered, that cut surfaces remaining exposed on the sides of the scion are covered, and that no air holes remain in the wax at the angle where the scions meet the stock. A small bit of wax should be placed on the tip of the scion to seal this cut end. A good brush wax is to be recommended for waxing the grafts.

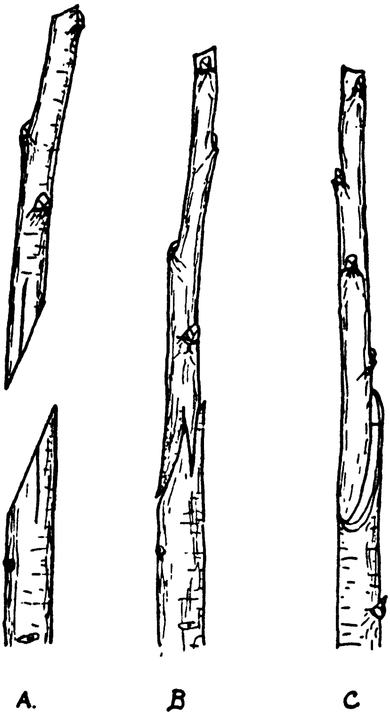

FIG. 77. The whip graft. A, shows scion and stock cut to match; B, scion inserted on stock; C, stock larger than scion. Shows scion set to one side to match up cambium layers.

Whip grafting. In top grafting trees, one may want to place grafts in limbs less than 1 inch in diameter. This is especially true when it seems advisable to graft small trees. Results from whip grafting are better when the stock and scion are of about equal size. In making a whip graft a sloping cut is made on one side of the upper end of the scion. A tongue is cut in both scion and stock midway in the sloping cut and with the grain of the wood. When the scion and stock are brought together, the tongues each slip into the slits made for them and are thus held together. The cambium layers of stock and scion should be matched so that they make contact with each other at the tongues. When the scion is smaller than the stock it must be placed to one side in order to do this. (Fig. 77.) If the work is carefully done, there is a possible contact of cambium on three surfaces. Since the stock is not large enough to exert much pressure towards holding the scion in place, this type of graft is usually wrapped to hold the parts securely together. Waxed yarn or cloth strips may be used for this purpose. Small rubber strips, $\frac{3}{16}$ inch wide by 5 inches long (preferably thin, wide strips), have recently been used for wrapping whip grafts and are ideal for this purpose, as they exert the necessary pressure to hold the parts together and expand with the growth. After the graft is wrapped, it is then thoroughly covered with a thin coating of brush wax. It has been found by experience that the rubber strips may have to be cut some time after the union has been established.

This method of whip grafting is used to some extent in growing young trees. Small seedlings of $\frac{1}{2}$ to $\frac{5}{8}$ inch in diameter are root grafted in this manner during the winter. Portions of the root or the whole root may be used for each scion. Although the growth of trees from piece roots may be as good as that from whole roots, the percentage of mortality may be greater with piece-root trees. The root grafts are then stored in a moist condition to callous, and are set out in the nursery row in the spring. Better growth is secured if the scion is cut so that the upper bud is directly above the tongue on the side where the cambial contact is made. (Fig. 77B.) Since root grafts are buried entirely, except for the upper bud of the scion, in setting in the nursery row, it is not necessary that they be waxed.

Bark grafting. Bark grafting is done in the spring when the bark peels readily. It is preferred by some to cleft grafting because it is done without splitting the wood. It is used also in grafting limbs that are larger than those usually cleft grafted. Its weakness lies in the fact that the grafts are not sufficiently supported and, if vigorous growth ensues, are likely to be blown and whipped out by the wind. Several methods of bark grafting are used, but all consist of placing the scions just under the bark. In one method largely used, the limb is cut off as for cleft grafting. The scion is cut with a long bevel on one side and a very short bevel on the other so as to leave a sharp chisel edge at the lower end. The scion is then held in place on the outside of the bark and the bark slit down with a knife to correspond approximately with the length and width of the bevel surface of the scion. The lower end of the scion with the long bevel towards the stock is then pushed under the bark between the two cuts, the bark peeling as the scion is pushed downward. The lifted bark is then cut away even with the top of the short bevel and the scion tacked tightly to the stock with two small nails or brads. (Fig. 78A, 1.) Other scions at intervals of 2 to 4 inches are put in place in the same manner entirely around the stub. The entire scions and cut surfaces of the stock are covered with melted wax. In shaping the scion, some prefer to cut halfway through the scion at the top of the long bevel, forming a shoulder that is placed against the top of the stock, giving added support to the scion. (Fig. 78A, 2.) Another method is to cut the scion to a very long slim bevel from one side, slip it down between the bark, and tack it in place. If the bark is heavy, it is necessary to cut the bark in front of the scion before it will loosen enough to allow the scion to be pushed down into place. The scion is then secured and waxed in the usual way. In placing scions in bark grafting, care must be

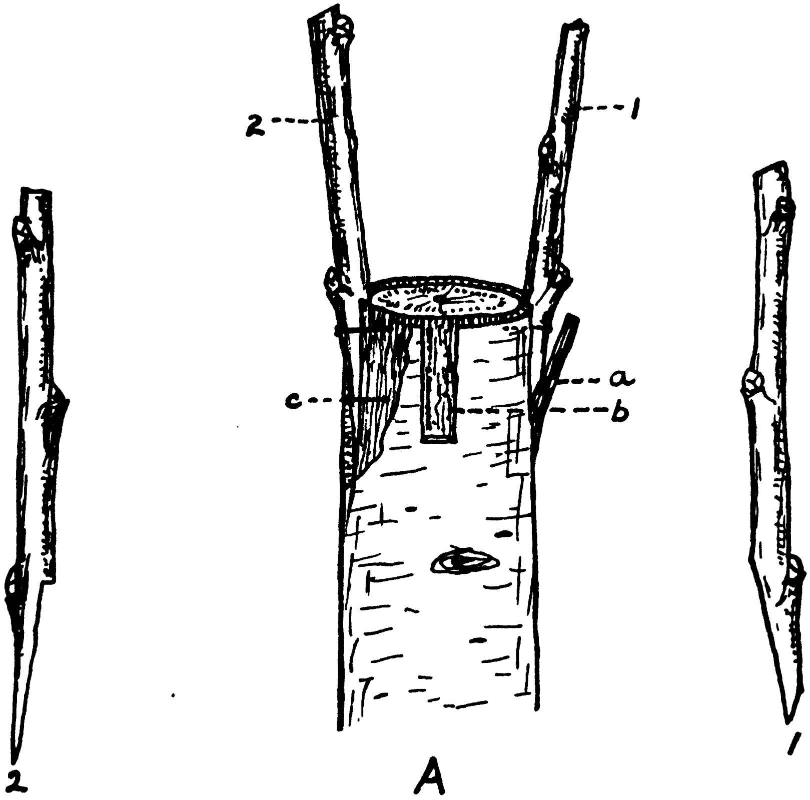

FIG. 78. A, shows two methods of shaping scion for bark grafting. Graft ready for waxing: a, indicates point where strip of bark is cut off. Strip of bark was lifted by scion when it was pushed into place; b, strip of bark cut and lifted out ready for scion cut with notched bevel; c, small nail or brad used to tack scion to stock. 1, scion shaped with long and short bevel; 2, scion cut with shoulder or notched bevel.

taken that they are cut with a smooth surface as nearly as possible to fit the surface of the stock. A small block plane has been found very valuable in smoothing up and cutting the long bevel in this type of grafting. The knife of the plane may even be ground to a slightly rounded cutting edge instead of straight. Thus the cut at the beveled surface of the scion is slightly concave and fits the surface of the stock more closely. The small nails or brads used in bark grafting should be very slender to avoid splitting the scion, and should have wide heads so as to draw the scion closely to the wood. Cigar box nails or the small nails used in making up bee supplies are very good for this purpose.

Bridge grafting. Bridge grafting is used to repair damage done to trees by mice, rabbits, or other bark peeling animals. It may be used to advantage in bridging over damaged areas of the trunk caused by blight cankers, winter injury, disease, or serious mechanical injury. Bridge grafting might be called a phase of bark grafting, differing mainly in the fact that both upper and lower ends of the scion are grafted into the stock or tree. In preparing the tree for bridge grafting the damaged bark should be cut back to clean, live, healthy bark. Scions of sufficient length should be selected to reach over the injury to healthy bark on either side, and extra length should be allowed for a bow or spring in the scion when finally set. Both upper and lower ends of the scion are beveled, and the bark on the stock measured and cut as for bark grafting. Care must be taken that the bevels on the scion are both on the same side. The lower end of the scion is fitted into the slot in the bark cut for it and secured with two small nails. The free end is then sprung down and fitted into the slot prepared for it on the upper side of the injured area, and this is nailed in place. Enough scions should be set over the injured area so that they will not be over 2 to 4 inches apart. Water sprouts or long 1-year terminal growths make good scions for bridge grafting. All cut surfaces should be carefully coated with wax. The upper ends of the scions should have special care as the wax tends to run off and leave uncovered spaces at the angle where the inner side of the scion meets the stock. The edge of the injured area should be covered with wax; sometimes, the whole surface of the injury is painted with melted paraffin or brush wax. Where the injury extends from the base of the tree out into the roots so far that bridging with scions is impossible, 1-year-old nursery trees can be planted at intervals around the base of the tree and the tops grafted into the healthy tissue above the injury. (Fig. 79.)

Bud grafting or budding. Budding is employed by nurserymen more than any other method in propagating a desired variety on seedling stock; apples, pears, cherries, quinces, peaches, and plums may all be propagated by this method. Orchardists often use budding in topworking the trunks or branches of small trees as well as in budding water sprouts or vigorous new growth in older trees. When grafts set in the spring have failed to grow, vigorous sprouts will usually grow out around the stub. A few of these more vigorous sprouts may be selected and budded in the late summer.

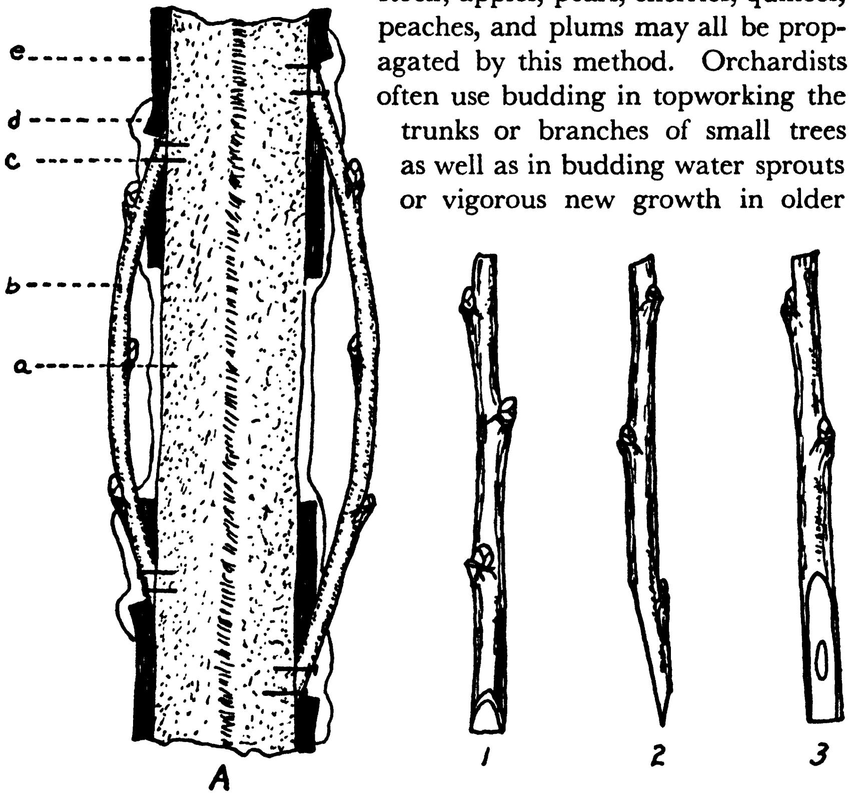

FIG. 79. A, longitudinal section showing details of bridge graft: a, wound; b, scion; c, small nail or brad; d, wax; e, bark. 1, base of scion showing short bevel; 2, base of scion showing side view of bevels; 3, base of scion showing long bevel.

The essential considerations in budding are the same as in grafting, except that a single bud is made to grow upon the stock instead of a scion containing 3 or more buds. The success of the operation depends upon the union and growth of the cambium of bud and stock. Shield or T budding is most generally used and takes its name from the shape of the small piece of bark cut off with the bud or the cut made in the stock. The exact time of budding depends upon the ripeness of the buds on the current season's growth and upon the ease with which the stock peels. Stocks should be in good growing condition and bark slipping easily for success in budding. Buds should be secured from the variety of fruit desired, the buds in the axils of the leaves on current-season growth being used. The buds should be well formed. Vigorous shoots having formed their terminal buds generally contain good mature buds. Buds taken from the central two-thirds of the growth are better than buds taken from the tip or bottom ends of the growth. These growths are cut from the tree and the leaves trimmed off, leaving about half an inch of the petiole of the leaf to act as a handle when inserting the bud. These sticks containing the buds are then wrapped in moist cloth to keep them fresh while budding. In budding seedling trees, the leaves are rubbed off and a smooth place in the bark on the north side of the tree as close to the ground as possible is selected for the place to insert the bud. In topworking, buds are placed in an outside position or on top of the limb. Buds are more successful when placed on current season or 1-year wood. With proper care buds may be grown on older wood. The thicker the bark the less likely the buds are to succeed.

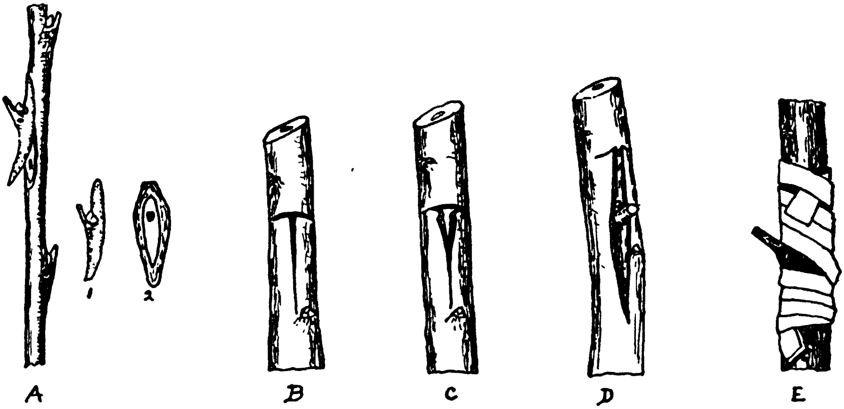

FIG. 80. A, showing bud stick with bud partly removed: 1, bud removed, front view; 2, bud removed, showing shield-shaped rear view; B, showing T-shaped slot cut in stock; C, T slot ready to receive bud; D, bud in place in stock; E, bud wrapped with rubber budding strip.

In shield or T budding, the cut in the stock is made in the shape of a T. The bark of the stock is first slit for a little more than an inch lengthwise of the stem. Next, the knife edge is rolled across the stem at the top of the lengthwise slit completing the T-shaped cut. (Fig. 80B.) If the crosswise cut is made with a downward slant of the knife, the corners where the two cuts cross each other may be raised slightly when the knife blade is brought out. If the bark does not raise up easily enough to admit the bud without injury by this method, the edges must be loosened and raised with the tip of the knife. The bud is now cut from the twig in the shape of a shield, starting the knife blade about ½ inch below the bud, cutting deep enough into the twig so as not to injure the bud, and running up under the bud and out again about ½ inch above the bud. (Figs. 80A, 81.) The small bit of wood cut out with the bark is sometimes removed, but ordinarily it is disregarded. The bud is now grasped by the projecting petiole, inserted in the T-shaped opening, and pushed downward into place. (Fig. 80D.) If the bark at the top of the shield projects above the cross cut, it should be cut off even, so that the under surface of the bud fits closely to the stock. The bud is then wrapped to hold it tightly against the stock until the union takes place. (Figs. 80E, 82.) Several wrapping materials have been used, among them narrow strips of cloth and raffia. More recently, specially made rubber budding strips have been made by rubber manufacturers and have been found to be very satisfactory.[75] The size of these strips varies from 3½ inches long and $\frac{3}{32}$ inch wide to 5 inches long and $\frac{3}{16}$ inch in width, according to the size of the stock and the length of time the wrapping is to remain. The great advantage of wrapping with rubber strips is that they maintain a constant pressure, expanding with the growth of the stock. These strips do not always rot off and may need to be cut, as is necessary with raffia or other wrapping materials usually used. In wrapping a bud, the wrap is started below the bud, crossing the first turn to hold it in place, continuing the wrap up to the bud, then above the bud, and placing the free end back under the last turn which holds the end in place. This method holds the bud tightly in place and makes a smooth wrap without the necessity of tying any knots. Three or 4 turns of the wrapping both below and above the bud are sufficient. No waxing of the buds is necessary. If the budding has been successful, the bud will have united with the stock at the end of about 2 weeks, the petiole will have dropped off, and the bud will have a plump, healthy appearance. If the wrapping material has not loosened

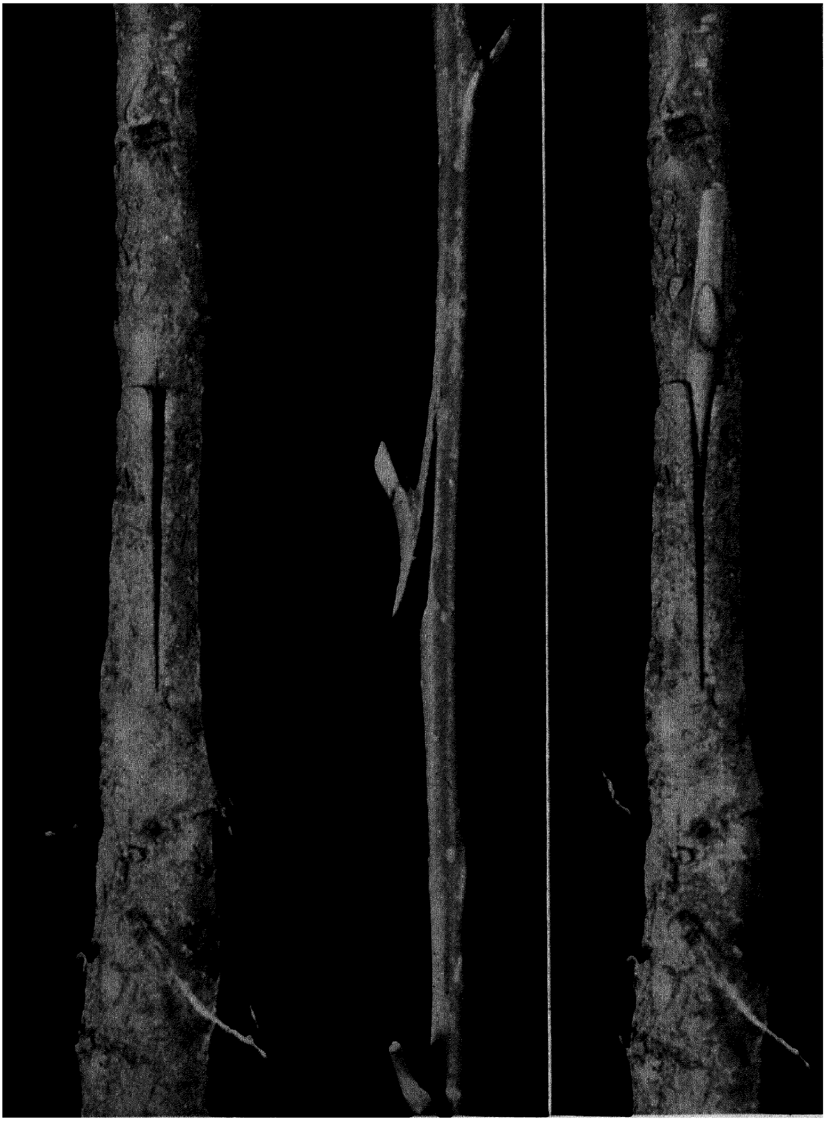

FIG. 81. Budding. Left to right: T-shaped incision in stock; bud stick with bud partially severed; bud placed in upper end of incision ready to be pushed into its proper position.

after several weeks it should be cut. The bud will remain dormant the remainder of the season but should start growth the next spring. The stock should be cut off just above the bud in the spring and care taken the first few weeks of active growth to remove all sprouts arising from the stock around or directly below the bud. The strength of the tree will go into the growth of the bud in this way; otherwise, the numerous sprouts may smother out the bud or cause it to grow weakly.

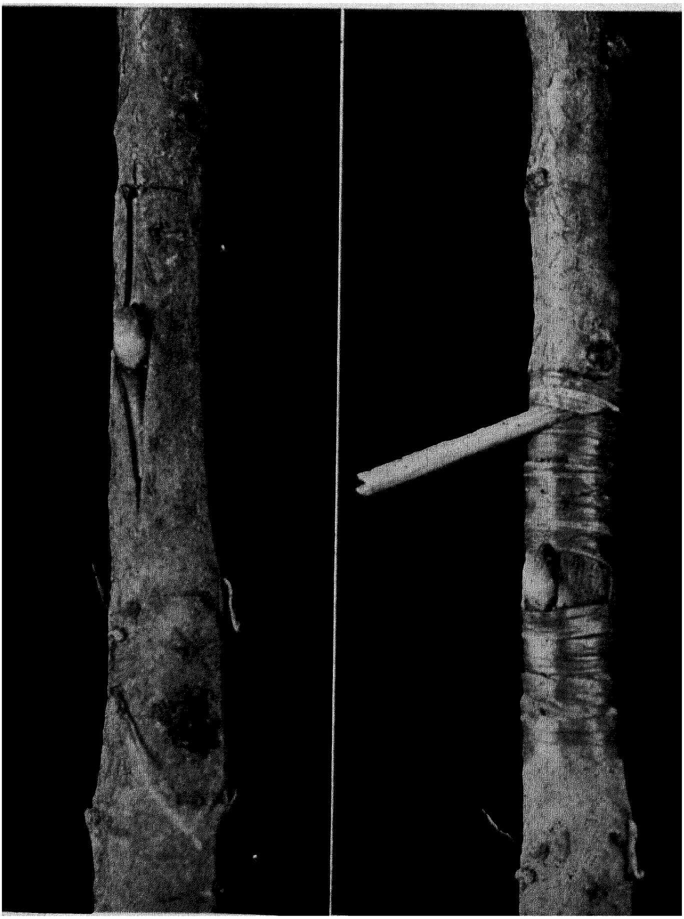

FIG. 82. Budding (*continued*). Left, bud in place in stock. Right, bud held in place with raffia.

Waxes used in grafting. Several kinds of grafting waxes are used in the operation. Most grafting waxes are combinations in some proportion of rosin, beeswax, paraffin, tallow, and linseed oil. One of the oldest formulas for grafting wax known to horticulture is that for hand wax, or soft wax. Most grafting wax becomes soft when heated, and this hand wax becomes soft enough to work at the temperature of the hands. It is kept workable in the orchard by holding it in the hands and working it between them.

Formula for hand wax.

rosin	4 parts
beeswax	2 parts
tallow	1 part

These materials should be melted together slowly and not allowed to boil. When melted and well mixed, pour into cold water to cool. Grease the hands well with tallow and pull the wax in the same manner as taffy until it is straw colored and uniform in texture. The wax may then be used or stored in rolls and in oiled paper. For use in very cold weather, ½ pint of linseed oil may be substituted for the tallow; this makes a softer wax. For a harder wax increase the amount of rosin.

Brush wax. Because of the inconvenience of working with sticky hands and the ease of applying brush waxes, waxes, applied in melted form, have increased in use tremendously. They are applied with a brush in melted condition and harden on the grafts after being applied. They flow into crevices, cover well, and can be applied in a thin coat compared with hand wax. Brush waxes are kept in melted condition in the orchard by means of small portable heaters of simple construction. Orchard-supply companies are now selling small heaters for this purpose, or they may be constructed at home by the orchardist.

High-melting-point paraffin has been increasingly used as an ingredient of brush waxes in the past few years. Plain paraffin, if applied alone, however, has a tendency to crack in cold weather and flake off. Satisfactory, commercial paraffin brush waxes may be purchased. "Parapin" wax sold by orchard-supply companies is one of the best. These waxes contain other ingredients mixed with paraffin to give it added elasticity and sticking qualities. The success of using paraffin alone as a brush wax after severe weather is past depends largely on applying it while almost smoking hot. It will then go on in a thin, almost transparent coat much like varnish and will stick remarkably well. A high-melting-point paraffin is preferred as it will not be affected by hot weather.

A formula for brush wax recommended by J. A. Neilson of Michigan both for coating scions and for brush wax in grafting is as follows:

Paraffin brush wax

rosin	1 pound
linseed oil	3 fluid ounces
paraffin	5 pounds

Melt the rosin and linseed oil together and pour into the melted paraffin. Mix well. Pour out into a shallow pan lined with oiled paper to cool in a cake 1 to 2 inches thick. This makes a convenient-sized cake which can be broken up and melted in a heater as wanted.

Another paraffin mixture used especially for coating scions and also suitable for covering grafts is: paraffin, 4 parts; pick-up gum, 1 part. It is important that these proportions of paraffin and pick-up gum be strictly adhered to. Pick-up gum is a gluelike substance sold by commercial manufacturers largely for glueing packages and for labels. This material is added primarily to keep the paraffin from flaking and to give it added adhesive qualities.

In grafting, these almost transparent brush waxes may be used in covering the entire scions, buds and all, as well as the cut surfaces of the stock. They may be used for coating young nursery stock before setting out to keep it from drying out or for coating scions or nursery stock for long shipment. By use of this wax on scions having latent buds that have not started growth, grafting may successfully be done even during the growing season. The covering of the entire scion eliminates any possible drying out even under adverse conditions. This method was first used in grafting nut trees where conditions had to be especially favorable. It gave such favorable results that it has since been used quite generally in the grafting of fruit trees.

Another brush wax that was considered standard before the use of paraffin and which is widely used and recommended where a tough lasting wax is wanted is:

Standard brush wax

rosin	5 parts
beeswax	1 part
linseed oil	¼ part
lamp black or powdered charcoal	½ part

Melt rosin slowly, add beeswax and melt, then add linseed oil. The mixture is then taken from the fire and the powdered charcoal or lamp black slowly stirred in, a little at a time. The charcoal or lamp black gives the wax toughness and pliability.

Asphaltic emulsions. Recently various water-soluble asphaltic emulsions have appeared under various trade names and have been used for covering wounds made in grafting. Several of these have been as satisfactory as standard brush waxes.

These emulsions may be easily applied cold with a brush. Since they dry out quickly upon exposure to air, it is advisable to use a container holding just enough for immediate needs. It is also necessary to keep the reserve supply covered with water to prevent deterioration through drying out. If the emulsion becomes dry and heavy, a small amount of water should be added and the mixture thoroughly stirred. If the mixture is thinned too greatly, it may be thickened with powdered asbestos.

Propagation of Specific Fruits

Grape. American grape varieties other than Muscadine (*Vitis rotundifolia*) are usually propagated by hard-wood cuttings taken from the plant during the fall or winter. Well-matured, 1-year wood of medium diameter is cut into 8- to 10-inch lengths including 3 buds. The usual procedure is to cut just below the lowest bud and an inch or more above the uppermost. The location of the lower cut is based on the fact that roots develop more profusely in the region of a node, and thus the cut just below the basal bud tends to stimulate such development.

The cuttings are stored in a moist, cool place usually with the basal end up to facilitate callousing. In the spring they are planted several inches apart and deep enough to cover all but one bud. The soil should be well prepared, moist, and well aerated.

Bench grafting is the most common method of propagating the grape on various roots. Both short and long whip grafts have been used. The short whip is made more easily and rapidly but should be used only when the grafts are calloused in a warm room (75° to 80° F.) because they are easily broken. For sand-callousing only the long whip should be used. Specific detailed directions for the propagation of the grape have been recently presented by Jacob.[39]

Recently Snyder and Harmon [59] have recommended the bud graft method where Vinifera varieties are to be grafted on rootstocks resistant to phylloxera and nematodes. It differs from the budding of other fruits in that along with the grape bud a considerable amount of woody tissue is also included.

Strawberry. During the growing season established plants send out long, slender stems in all directions. These runners are 8 to 16 inches long, and roots develop at each alternate node which is in contact with the soil. After the roots have become established the slender stem connecting the rooted portions dies. These young plants are usually dug the following spring and set in the bed where they are grown for a year before being allowed to fruit.

Varieties differ considerably in the number of runners produced, while environmental conditions, such as duration of light, water, and nutritive materials, are also important factors. The period of runner formation extends from June until November in the North, with the greatest formation taking place in August.

Black and purple raspberries. The black and purple raspberries are propagated by tip-layering. For the best results the tips should be carefully inserted in the soil by hand. At the time preferable for layering the tip portions lengthen out, having a "snaky," "rat-tail" appearance, and small, curled leaves.[58] Early tipping is preferable since late tipping may result in several small plants from sublaterals rather than one new plant with a well-developed root system. Since all tips are not ready at the same time, the plantation must be gone over more than once. The tips are preferably inserted in a vertical rather than a horizontal position and then covered with 3 to 4 inches of soil. If the operation is carried out in mid-August to early September they should be well rooted by the end of the season. They are left attached to the plant over winter, and in the spring 4 to 8 inches of the parent is severed along with the rooted tip. The young plant may be grown in the nursery for a year and sold as a transplant. Tips are delicate and easily injured and great care should be used in shipping and handling. In propagating the black raspberry there is no particular value in selecting especially productive canes or extra large tips, provided the parent plant is free from disease.

Red raspberry. The red raspberry is propagated by means of suckers growing from the roots. They may be set directly into the plantation or grown in the nursery, after which they are known as transplants. Large suckers or transplants are no more preferable than small ones as far as the stand is concerned, and they usually cost more.

Frequently the young, green suckers, several inches high, are dug early in June, care being taken to obtain a portion of the old roots as well. The production of an abundance of sucker plants may be stimulated by striking a spade into the ground around the old plants, or by deep cultivation which severs the roots. Growers who raise their own plants will find it preferable to set aside a portion of their field for propagation purposes since otherwise the old plants may be injured.

Blackberry (upright). The upright blackberry is propagated chiefly by root cuttings, preferably 3 to 4 inches in length and about the thickness of a lead pencil. They are usually removed in the fall and then stratified in moist sand or other suitable media. When set in the nursery row they are placed in a trench horizontally and covered with several inches of soil. If they are of the preferred size they may be spaced 3 to 6 inches apart, and after a year in the nursery they are set out permanently. The blackberry may also be propagated by suckers, but the nurserymen prefer root cuttings.

Himalaya berry, phenomenal berry, trailing blackberry, dewberry, loganberry, and youngberry. These fruits are commonly propagated by tip-layering. In California the ends of the canes are covered with earth during the latter part of the summer, and rooting develops rapidly enough to permit planting the following spring. The youngberry does not root as readily from the tips as other types.

Currant and gooseberry. Both these fruits are usually propagated vegetatively by hard-wood cuttings, the gooseberry by soft-wood cuttings and mound-layering as well. Hard-wood cuttings usually vary from 5 to 14 inches in length and include several buds. If close together, no special attempt is made to cut either below or above the bud, but if rather far apart the upper cut should be made a short distance above one bud, and the lower immediately below another. The same provisions are made for storing and planting the cuttings as in the case of the grape, quince, and other plants rather readily propagated from hard-wood cuttings.

Varieties of gooseberry differ in their response to the different methods of propagation. Those of European parentage are usually more difficult to root from cuttings, although American varieties also differ in this respect. Poorman and Houghton are readily propagated from cuttings.

When the gooseberry is propagated by mound-layering which is preferable for certain varieties, the mounding is not begun until vigorous shoots have been produced from the cut-back portions. If mounded in July the shoots should be well rooted by fall, after which they are usually grown in the nursery for 1 or 2 years before being placed in a permanent location.

Blueberry. The rooting of the highbush blueberry (*Vaccinium corymbosum*) requires special attention to aeration, temperature, moisture of the propagating medium, and proper humidity within the frame.[10, 40] In addition, suitable light and temperature are essential. A high percentage of rooting requires considerable equipment and almost constant attention over a relatively long period. Hard-wood cuttings from the previous season's growth are taken in late winter or early spring. They should be fairly thin, 3 to 4 inches long, and should consist only of leaf buds. The cuts should be made in a slanting direction immediately above the upper bud and below the lower one. Cuttings more than ¼ inch in diameter seem to root less readily than smaller ones, but large, vigorous plants are produced when it can be accomplished.

The cuttings are next placed in a propagating frame containing German peat or peat (75 per cent) and sand (25 per cent) where they are left until well rooted. Johnston [40] found that a box type of frame was preferable to others, including the cold frame. The air must be kept humid and the plants shaded. Ventilation is provided when they have started to root in late June or July. The plants may be carried through the winter out of doors if proper protection is given.

Soft-wood cuttings are also used. They should be taken as soon as the secondary growth starts, which, in southern Michigan, is early in July. The procedure in this case is similar to the hard-wood method. Varieties differ considerably in facility of rooting.

The blueberry may also be propagated from seed. If the seeds are planted as soon as removed from the mature fruit they will germinate in 5 to 8 weeks. Although they may be sown outside, the better procedure is to place them in trays of peat, keeping the young seedlings in the greenhouse through the winter and setting them out in the spring.

STOCKS IN RELATION TO SPECIFIC FRUITS

The Apple

Seedling stocks. Seedling stocks for the apple have been derived from what are called French Crab, from standard apple or crab-apple varieties, and seedlings of crab species.

French Crab. Originally the seed was collected in France from cider pomace, and sown either in nurseries in that country or in Vermont and Kansas in the United States.[69] At present seedling trees from Europe are no longer permitted entry because of quarantine restrictions. Within the last decade the supply of seed has been supplemented by an ever-increasing amount collected in this country and sown in Kansas and the Pacific Northwest. Here it consists of a mixture of unknown but of undoubtedly standard commercial varieties. In France also the term crab is somewhat of a misnomer since the seeds have not been limited to crab-apple but are a mixture of unknown varieties.

Despite the fact that these seedlings have been obtained from a mixture of varieties, all of which are heterozygous, the trees in commercial orchards in America have, in general, been surprisingly uniform. This uniformity is undoubtedly due in part to the fact that the seedlings which eventually become vigorously growing nursery trees are, in reality, the result of an unconscious selection from the large numbers found in the pomace or apple refuse. During washing, planting, and transplanting, a possibly unintentional, but no less important, selection of good seeds and seedlings took place. This is, in part, an explanation of the results obtained in various experiments concerned with uniformity in growth of trees on seedling and on clonal stock. Trees on French Crab seedlings have shown only slightly more variability at the most than the same varieties on clonal rootstocks.[6, 79]

The data obtained from such experiments indicate that there is not sufficient increase in uniformity of trees on clonal stocks to justify shifting from French Crab seedlings for that reason alone.

Seedlings of standard apple and crab-apple varieties. Seedlings of specific commercial varieties as well as seedlings of crab-apple varieties have been used experimentally as understocks, and in a limited way commercially.

Although many varieties will produce vigorous seedlings, only those are valuable which excel the French Crab in some particular respect such as hardiness. Delicious, Winesap, Jonathan, York Imperial, Ben Davis, and Rome Beauty produce vigorous seedlings but are not of sufficiently uniform hardiness to justify their use, in preference either to the commonly used French Crab or the hardier varieties, Whitney (crab-apple), Wealthy, Pewaukee, McIntosh, Malinda (crab-apple), Allen Choice, Tolman Sweet, and Windsor, which produce outstandingly good seedlings.[50] Even McIntosh seedlings are not of equal hardiness, nor are Delicious sufficiently cold-resistant. Virginia Crab and Hibernal, though very hardy, unfortunately produce worthless seedlings due to their triploid chromosome constitution. The fact that all triploid apple varieties produce worthless seedlings eliminates such varieties as Stayman Winesap, Baldwin, Stark, Gravenstein, and Rhode Island Greening (see additional varieties in Chapter 10) as seedling understocks.

At present seedlings of the outstandingly hardy Russian variety Antonovka are greatly preferred in Canada to any other variety, and in Eastern Ontario and Quebec seedlings of this variety are recommended as stock for standard commercial varieties.[18] Seedlings of Antonovka are reported to be outstanding in their uniform hardiness.

In Canada seedlings of the crab-apple varieties Columbia and Osman, which are hybrids of the Siberian crab with standard varieties, are very hardy and are compatible with ordinary commercial varieties. In addition, Beauty, Olga, Bedford, Dolgo, and Florence crab-apples are reported to produce satisfactorily hardy seedlings.[44, 45]

As yet there are no clonal rootstocks propagated from seedlings of a known apple variety which have received sufficient trial for commercial recommendation.

Crab species. Within recent years seeds of certain crab species such as *Malus baccata* (Siberian Crab), *Malus baccata* var. *mandshurica* (Manchurian Crab) and *Malus prunifolia* var. *robusta* have been used in a limited way where hardiness of root is an outstanding necessity.[1, 18] The increased use of such stocks is the result of increased demand for a stock which will withstand cold in the North Central states, the Great Plains area, and the Upper Mississippi Valley.

General experience indicates that Siberian Crab seedlings tend to be rather nonuniform, and may considerably dwarf the standard varieties to which they are budded or grafted. The trees come into bearing somewhat earlier but they seem to be fully compatible with all varieties to which they have been worked. They are not as vigorous as French Crab or as deep-rooted as some of the more vigorous seedlings of hardy Russian varieties such as Antonovka. They are also quite susceptible to fire blight. Consequently, it has been recommended that the Manchurian Crab be used in preference to the Siberian Crab, since the seedlings are more uniformly vigorous and there is less dwarfing of the top. Alderman [1] has in fact concluded that it is a "little more satisfactory to use seed of some of the best and most vigorous crab-apples rather than *baccata*." He reports that nurserymen in Minnesota prefer any crab-apple seed to *baccata* and in view of this are using seed of standard apple varieties such as Wealthy, Haralson, and Patten Greening. On the other hand, within recent years certain nurserymen in the Upper Mississippi Valley have used seedlings of *M. baccata* and *M. baccata* var. *mandshurica*, and as far as is known at present satisfactory trees will be produced therefrom.

Specific varieties as rootstocks (own-rooted). Specific varieties of apple have not been commonly used as rootstocks by nurserymen, due to the difficulty with which roots are obtained upon stem or root cuttings. Northern Spy is practically the only variety which has been used in any part of the world, even to a limited extent, as a rootstock in commercial orchards. In Australia, New Zealand, and South Africa because of the resistance of its roots to attacks of the wooly aphis (*Schizoneura lanigera*) it has been used as the understock upon which several standard varieties have been budded or grafted. It has not, however, given complete satisfaction, and extension of the variety to new plantings in any part of the world is improbable.

Northern Spy. In the first place, Northern Spy, like other commercial varieties, is difficult to propagate vegetatively, and requires special methods. Strangely enough, although a tree of Northern Spy grown on French Crab rootstock becomes very large, when used itself as a rootstock it dwarfs the varieties topworked upon it. Experience in England indicates that it falls into the semidwarfing group, somewhat similar in effect to Malling Type II.[34] After 15 years at East Malling the trees on Northern Spy were much less vigorous than those on the "vigorous" and "very vigorous" layered Malling stocks. In Tasmania trees on Northern Spy had to be reinvigorated by means of inarching seedlings. This dwarfing effect would not be considered of serious consequence where semidwarf trees are desired, if the root system were only satisfactory. However, at East Malling the root system tended to be weak, sparse, poorly developed, and the main scaffold roots decidedly shallow. In general this rooting system is not adaptable to a wide range of environment.

Delicious. This variety has been used only experimentally as a rootstock and has not shown itself to be superior in any respect. Grimes Golden on Delicious own-rooted trees at the Indiana Station showed considerable mortality, while those which survived were only fairly vigorous.

It has now been established that this mortality was associated with or caused by the fungus *Phytophthora cactorum* (L. and C.) Shroet.[11] The disease spreads rapidly up the tree trunk, extending to the crotches in one season.

Virginia Crab and Hibernal. Although these varieties are budded or grafted by the nurserymen on French Crab seedlings, they have been used experimentally on their own roots as understocks for several varieties. At the Indiana Station,[16, 52, 53] Grimes Golden topworked upon these varieties made greater growth, and more individuals survived over a period of years than the same variety upon own-rooted rootstocks of Delicious, Oldenburg, Wealthy, Yellow Transparent, and Livland.

In Iowa, Dudley, Hibernal, and Virginia Crab were own-rooted as well as budded and grafted upon French Crab seedlings and then topworked to Jonathan, Grimes Golden, Delicious, Sharon, and Secor. The largest trees were grown upon Virginia Crab, intermediate on Hibernal and dwarfed upon Dudley. Varieties on the own-rooted Virginia Crab rootstocks were larger than those doubleworked on French Crab. In Hibernal there was no outstanding difference between the own-rooted and the doubleworked trees.[50]

Other varieties. Grimes Golden upon own-rooted Fameuse and Oldenburg at Indiana showed high mortality, while only a small loss occurred on Wealthy, Livland, and Transcendent.[16]

Stuart presented data concerning the cold hardiness of the scion roots of 50 apple varieties as determined in controlled laboratory tests.[64] The varieties were grouped into "very hardy," "relatively hardy," and "relatively tender" as follows:

Very hardy: Haralson, Virginia Crab, Hibernal, Oldenburg, Milton, and Yellow Transparent.

Relatively hardy: includes Northwestern Greening, Red Astrachan, Fameuse, Transcendent, Crimson Beauty, McIntosh, Gallia Beauty, Rome Beauty, Delicious, Cortland, Melba, Turley, and Wealthy.

Relatively tender: includes Jonathan, Williams, Winter Banana, Tompkins King, French Crab seedlings, Esopus Spitzenburg, Yellow Newtown, Yellow Bellflower, Northern Spy, Stayman Winesap, Rhode Island Greening, Baldwin, Grimes Golden, Arkansas, Fallawater, Stark, Roxbury Russet, and Gravenstein.

It is to be noted that roots from all the varieties classified as very hardy or relatively hardy were more resistant to low temperature than French Crab seedling roots.

In general it may be said that until a cheap and effective method is developed for inducing scion roots, Hibernal and Virginia Crab will continue to be budded or grafted upon French Crab or some hardy seedling rootstocks.

Intermediate stocks. A stock which intervenes between the root and the scion is rather commonly used in the propagation of the apple. Thus when a variety, no longer desired, is topworked, the original variety becomes the intermediate stock. Doubleworking of nursery trees of both the apple and pear has been practiced for some time. Grimes Golden is probably the outstanding example of the former, while dwarfing certain varieties of pear can be satisfactorily accomplished only by use of an intermediate stock. Furthermore, the recent practice of grafting blight-susceptible European pear varieties upon the resistant Old Home framework has become an outstanding example of the value of this procedure.

On the other hand certain problems have developed in connection with the use of intermediate stocks, and they have received considerable attention during the last ten years. In the first place results obtained from doubleworking Grimes Golden trees were not entirely satisfactory.[52] In order to alleviate the collar rot appearing at the base of the trunk, an intermediate stock of a variety such as Delicious was employed. The buds or scions of Grimes Golden were originally set part way up the trunk, since it was assumed that the injury would occur only at the base. Experience has shown, however, that the intermediate stock must also include the crotches of the tree if the injury is to be overcome by this means. The practice now is to insert the scions of the commercial variety at least 18 inches to 2 feet from the trunk.

The choice of appropriate intermediate stocks presents a second problem. The primary concern in relation to the apple is hardiness, since the recent severe winters resulted in injury to the trunks and crotches of certain varieties.

Hardy intermediate stocks. Maney and his coworkers in Iowa have presented evidence covering the longest period in regard to varieties suitable for hardy intermediate stocks.[49] Hibernal, Virginia Crab, and Haas are the most outstanding hardy varieties. Budded, in most instances on French Crab, they have withstood excessive heat, drought, and cold for over forty years. In addition they are quite disease-resistant, generally compatible with a wide range of varieties, and the crotches are characteristically wide-angled. Other hardy varieties which have been found in Iowa to be satisfactory for double working are Haas, Sheriff, Malinda, Antonovka, and Tolman Sweet (the latter is very susceptible to blight).

Aside from Hibernal, Antonovka is the intermediate stock most commonly employed in Eastern Canada, where hardiness is a prerequisite. Antonovka is also extensively used in Poland for double-working. Among recommendations, especially where sun-scald is a factor as in Manitoba, the following varieties are suggested for trial by Leslie: Beauty, Anaros, Florence, and Garnet Crab.[44, 45] In this region Virginia Crab has proven very susceptible to fire blight and Hibernal to sun-scald.

Still other varieties which are generally successful when top-worked do not, on the other hand, possess the degree of hardiness characteristic of the above, and consequently are not recommended as intermediate stocks for a new planting. Furthermore, certain incompatibilities, not yet fully determined, are apparent from experience. In Pennsylvania, Northern Spy has proved a failure as an intermediate stock for York Imperial, while both Northern Spy and Winesap are reported to be of no value for Stayman Winesap.[4] In fact the experience of growers, which is the chief source of information of this kind, shows that Northern Spy tends to be incompatible with certain varieties, although Grimes Golden for instance was reported satisfactory on this stock. Rome Beauty and Wealthy were not compatible in spite of the fact that growth continued for 7 to 12 years before the trees died.

Experience with Hibernal and Virginia Crab as intermediate stock, and even on their own roots, indicates that the two varieties differ in:[48, 50] (1) compatibility with the different varieties to which they have been budded or grafted and (2) size of trees at maturity.

1. *Compatibility.* Although in general a considerable number of varieties are compatible with both Hibernal and Virginia Crab, as indicated by the data presented by Maney in Table 30, yet certain combinations are incompatible. One outstanding difference is their reaction to the varieties of the Winesap group. All the members of that group are compatible with Hibernal. On the other hand Stayman Winesap shows a weak growth on Virginia Crab while Winesap is much dwarfed and is also more or less incompatible. On the contrary, Paragon, as opposed to Arkansas, makes a very vigorous growth. Turley does well also.

2. *Size.* General experience shows that these two varieties do not produce trees of equal vigor. In Iowa, Virginia Crab resulted in very vigorous trees, Hibernal in medium-sized trees, while Dudley had a dwarfing effect.[50]

These data, with the exception of Willow Twig, indicate that head diameters of trees of the varieties on Virginia Crab were, roughly, 25 per cent greater than the same on Hibernal. Exceptions may appear as further evidence is accumulated. It is reported, for example, that while Rhode Island Greening is compatible with Virginia Crab, the trees are dwarfed somewhat in comparison with other compatible varieties.

TABLE 30. STOCKS USED SUCCESSFULLY IN TOPWORKING APPLE VARIETIES

(*From Maney*)[48]

(In each case variety *italicized* is the scion)

Arkansas (*Mammoth Black Twig*)
Hibernal
Baldwin
Hibernal, Virginia Crab, Tolman Sweet, Transcendent, Whitney
Ben Davis, Gano, and Black Ben Davis
Hibernal, Virginia Crab, Borovinka, Borsdorf, Haas, Henry Clay, Northwestern Greening, Oldenburg, Tolman Sweet
Cortland
Hibernal
Delicious
Hibernal, Virginia Crab, Brier Sweet, Fall Orange, Minnesota Crab, Oldenburg, Patten Greening, Shields Crab, Transcendent
Early McIntosh
Hibernal, Virginia Crab
Golden Delicious
Virginia Crab

TABLE 30. STOCKS USED SUCCESSFULLY IN TOPWORKING APPLE VARIETIES—*Continued*

Gravenstein
Virginia Crab, Fameuse, Northern Spy, Tolman Sweet, Wolf River
Grimes Golden
Hibernal, Virginia Crab, Charlamoff, Golden Russet, Haas, Northern Spy, Oldenburg, Patten Greening, Peerless, Sheriff, Transcendent, Walbridge, York Imperial
Jonathan
Hibernal, Virginia Crab, Fall Orange, Haas, Henry Clay, Oldenburg, Patten Greening, Scott's Winter, Sheriff, Tolman Sweet, Transcendent, Walbridge, Wealthy
McIntosh
Hibernal, Virginia Crab, Baldwin, Malinda, Patten Greening, Stark, Tolman Sweet, Transcendent
Macoun
Hibernal, Virginia Crab
Maiden Blush
Virginia Crab
Melba
Hibernal, Virginia Crab
Northern Spy
Hibernal, Tolman Sweet, Wolf River
Northwestern Greening
Hibernal, Virginia Crab
Paragon
Virginia Crab
Rhode Island Greening
Hibernal, Virginia Crab, Haas
Rome Beauty
Hibernal, Virginia Crab, Ben Davis, Oldenburg, Whitney
Stark
Hibernal
Stayman Winesap
Hibernal, Baldwin, Borsdorf, Brier Sweet, Fall Orange, Red Astrachan
Steele's Red (*Canada Red*)
Tolman Sweet
Turley
Hibernal, Virginia Crab
Wealthy
Hibernal, *Malus baccata*, Transcendent, Wolf River
Willow Twig
Hibernal, Virginia Crab, Blue Anis, Oldenburg
Winesap
Hibernal, Akin, Ben Davis, Northwestern Greening, Northern Spy, Sheriff, Winter Banana, Yellow Newtown
Yellow Newtown
Northern Spy, Tolman Sweet
Yellow Transparent
Virginia Crab, Anisim, Fall Orange
York Imperial
Hibernal, Red Astrachan

The Malling stocks. The Malling stocks which are the best known vegetatively propagated rootstocks have been named in reference to the East Malling Research Station in England. There Director R. G. Hatton and his coworkers collected the various stocks in use in that country and separated them into what are called types, sixteen of which are now designated by Roman numerals. In reality, these types are separate varieties. Maurer of Berlin has recently presented a complete and well-illustrated description of the tree and fruit characteristics of these and other stocks.[51]

Various English varieties were then grown upon these stocks and over a period of years considerable data have accumulated with respect to their growth and fruiting. The cross-sectional area of the trunk, earliness of flower formation, fruit-setting characteristics, yield, and quality of the fruit and root growth have all been carefully observed. Two types resulted in extremely dwarf trees, while several permitted very vigorous growth. The remaining types made an intermediate growth which could roughly be classified into two groups. In consequence, Hatton divided the stocks into four groups: very dwarfing, semidwarfing, vigorous, and very vigorous.[29] The name under which these stocks have been known, together with the general growth response of the tree, is given in table 31.[29, 73]

TABLE 31

Malling No.	*Name of Stock*	*Growth Response*
VIII	French Paradise	very dwarfing
IX	Jaune de Metz, Yellow Metz	very dwarfing
V	Doucin Amélioré, Improved Doucin (England)	semidwarfing
VI	Nonsuch Paradise (Rivers)	semidwarfing
III	Unnamed (Malling Hollyleaf)[51] common stock, widely distributed in Europe	semidwarfing
IV	Holstein Doucin or Dutch Doucin	semidwarfing
VII	Unnamed—little used but long known in English nurseries	semidwarfing
X	Unnamed—Doucin U1 of Späth	semidwarfing
II	Doucin, English Paradise, Doucin (French nurseries)	semidwarfing
I	Broad-leafed English Paradise (of Rivers)	vigorous
XI	Unnamed (Green Doucin)[51] English origin from crab stocks	vigorous
XII	Unnamed—English origin from crab stocks	very vigorous
XIII	Unnamed—(Black Doucin)[51] Doucin U2 of Späth	very vigorous
XIV	Unnamed—Doucin U5 of Späth	very vigorous
XV	Unnamed—Doucin U6 of Späth	very vigorous
XVI	Unnamed—Doucin U3 of Späth Ketziner's Ideal—Standard vigorous stock of Germany	very vigorous

These types include varieties long used in Europe as well as others which are of no consequence. Prior to the work of Hatton, the various stocks used for dwarfing were badly mixed. After a survey of fruit plantations in Kent, he found that the common form of "Paradise" was, in reality, a mixture of Types II, III, IV, and V. It is believed that at one time or another the dwarfing stocks used in America have included Types VIII, IX, V, II, and III. Keeble and Rawes [41] state that at present in England the types used for dwarfing are IX, II, I, and VI, while Types XII, XIII, and XVI are recommended where very vigorous "well-anchored" trees are desired. Apart from Type IX, now commonly used to produce dwarf trees in America, the others have been of little importance either in commercial or home orchards, or in suburban gardens.

In America the chief interest in these Malling stocks lies in the size and yield which might be expected from American varieties worked upon these stocks. Many fruit growers would prefer to grow trees which are somewhat smaller at maturity than those which develop on French Crab seedlings. It is this viewpoint rather than a desire for greater uniformity that has occasioned interest in these stocks.

Information regarding size and yield is obviously supplied chiefly by English experiments [28, 31] although recently a report of trees growing for ten years on these stocks was presented in Massachusetts.[60] The questions of predominant interest are: (1) what is the comparative size of trees on French Crab and on the very vigorous stocks such as XII, XIII, and XVI? (2) what degree of dwarfing will be induced when American varieties are grown on the vigorous and semidwarfing stocks Types I, II, and IV?

English experiments. Following sixteen years of observation, Hatton reported [29] that trees of all varieties growing on those stocks included in the very dwarfing and very vigorous groups still differed widely in the degree of growth which they had made; the trees on Types VIII and IX were very dwarfed, while those on XII, XIII, XV, and XVI were very vigorous, regardless of the scion variety. On the other hand those stocks included in the semidwarfing and vigorous groups varied considerably in relative growth, largely in response to the variety to which they had been budded or grafted. Furthermore, as time passed the relative order of growth of varieties on these stocks varied considerably. For example, although Type

II is usually classed as "semidwarfing," trees on this stock, as they grew older, became larger than those on the "vigorous" stock I. This fact has been substantiated in Canada.[76]

Furthermore, all varieties on Types IX, VII, XII, and XVI showed the same relative growth, with the trees on XII becoming the largest. As verified also by experiment in America, Type I is very dwarfing with some varieties (probably incompatible) while considerable growth is made with others.[29, 31]

A comparison was also made of the relative growth of scions of Lane's Prince Albert on these stocks and on vegetatively propagated selections from French Crab seedlings. The trees on Type XII were distinctly larger than the trees on 4 out of 5 clonal French Crab stocks. The trees on Type XVI were nearly as large as those on XII, a relation which has been verified in the American experiments.

American and Canadian experiments. In America data concerning the effect of American varieties on these stocks have been presented from Massachusetts [57, 60] and Ontario.[76] The oldest experiment, that in Massachusetts, is concerned with the growth of McIntosh and Wealthy upon several of these Malling stocks.

The trees on Malling XII and XVI were larger at the end of the 10-year period than those either on seedling (French Crab) or on their own roots. Type I while semidwarfing for McIntosh was incompatible with Wealthy. At the end of the period the cross-sectional area of the trunks of the trees of McIntosh on I was approximately 58 per cent of that of the trees on XII and 73 per cent of that of the trees on seedling roots. This comparison indicates the extent to which Malling I dwarfed the trees. Type II dwarfed McIntosh to a greater degree than I, while the trees on Malling IV were considerably larger. Both varieties on Malling XVI significantly outyielded the trees on the other stocks at the end of 10 years.

Upshall in Ontario has reported the growth and yield of five varieties on several Malling stocks up to the end of an 8-year period.[76] The trees of Northern Spy, Delicious, and McIntosh were larger on French Crab than on Malling XVI. On the other hand, Melba and Rhode Island Greening trees were larger on XVI than on French Crab. Those on Malling I were smaller than on Malling II. Except in the case of Melba the yield on II was higher than on I. The trees on Malling XVI were lowest in yield up to the time of the report due to their vigorous growth.

The data available at present indicate that American varieties on Malling XII and XVI, which are probably the most widely compatible of the very vigorous group, will develop into trees as large or larger than those on French Crab seedlings. Undoubtedly Malling I and II will result in considerable dwarfing and in some instances I is incompatible. These experiments have indicated that only by growing each variety on Malling I can such incompatibilities be ascertained. Furthermore, varieties differ considerably in the growth that they make upon Malling II. Not only do the stocks I and II but also the very vigorous Malling XIII show differences in soil and climatic adaptation in the United States and Canada. The general conclusion has been reached by those engaged in these experiments that the rootstock must not be considered apart from the soil and variety to which it is budded or grafted.

The Pear

Until recently varieties of the European pear (*Pyrus communis*) were largely grafted or budded upon seedlings grown from seed obtained in France. There the seed was removed from pomace of the Perry pear (*P. nivalis*) and from fruits of European varieties. At present, however, the seed of standard European varieties grown in the United States is furnishing an increasing number of the seedlings for use in this country. There is a particular demand among nurserymen for Bartlett, although Winter Nelis, another European variety, is said to be equally satisfactory.[69] Unfortunately, these seedlings, particularly Bartlett, tend to be relatively susceptible to blight (*Bacillus amylovorus*).

The problem of obtaining hardy as well as blight-resistant understocks for the pear has not been satisfactorily solved. As yet no understock has been obtained which will supplant seedlings of *Pyrus communis.* Seedlings of the oriental species, *P. serotina*, *P. betulaefolia* and *P. ussuriensis* have been used both as understocks and as intermediate stocks. Due, however, to the susceptibility of the European varieties to the black-end disorder as well as to incompatibility when grafted or budded on these stocks (with exception of *P. Calleryana*), their use has been discontinued.[35, 56] The same susceptibility occurs when European varieties are placed upon Kieffer seedlings (*P. serotina* x Bartlett) which have been rather extensively used in the South and the Pacific Coast area. Otherwise, the trees make excellent growth. Thus it has become evident that only varieties such as Kieffer, Garber, and Le Conte with oriental pear inheritance can be budded or grafted upon seedlings of oriental species.

Blight-resistant intermediate stocks. Recently Old Home, supposedly a European variety, has been used extensively in the Pacific Coast states and British Columbia as the intermediate stock for Bartlett.[19, 66] This variety, in itself, produces fruit of poor quality, but nevertheless it forms a compatible union with various European varieties and is vigorous, hardy, and definitely blight-resistant. It is budded on French or American seedlings and is then set relatively low in the orchard in order to stimulate rooting from the intermediate stock, thus contributing its blight-resistant characteristics to the roots also. The trees are then allowed to grow until the laterals reach at least 18 inches, at which time they are budded to the desired variety. While Old Home has been found susceptible to a disease known as bacterial canker, which is active during the dormant season in California, it is not yet of consequence to pear culture in the East. Another stock known as Lemon has been used in California. Although it is not susceptible to bacterial canker it is found to be less blight-resistant than Old Home. It is vigorous, upright-spreading, easily propagated, and compatible with Bartlett.[66]

Dwarf pears. Quince stocks (*Cydonia oblonga*, Mill) are used for dwarfing pears. Of these the Angers quince (known as East Malling Type A) is most frequently used, while the common quince (East Malling Type B) is of secondary importance. Other quince types have been tested at East Malling but only A, B, and C have any value as stocks.[27, 30] B induces slightly better yields and slightly greater vigor than A, while C which has a dwarfing effect, is particularly valuable for the light-bearing varieties, Doyenne du Comice and Pitmaston Duchess. The range in vigor and yield exhibited by the others is considerable, but they are found to be incompatible with many pear varieties.

In fact it has been thought for some time that even the quince types commonly used are not equally compatible with all varieties, and as a result an intermediate stock has been recommended for certain combinations. Varieties which presumably require double-working are Beurré Bosc, Winter Nelis, Sheldon, and Souvenir de Congrés. For this purpose Beurré Hardy in the United States and

Pitmaston Duchess in England are recommended as excellent intermediate stocks. Some nurserymen prefer to use an intermediate stock for Bartlett and Seckel as well, since the quince stocks do not appear to be uniformly compatible. The variety Duchess d'Angouleme as well as many others appear to be perfectly compatible with quince stock.

Dwarf Apple and Pear Trees

Dwarf apple and pear trees, although more extensively used abroad, have been planted in home gardens in this country for many years. While they have never been successfully adapted to commercial orchards, they do have value where space is limited and where a small quantity of several kinds or varieties of fruits are required. Although the amount of fruit is only proportional to the size of tree, the trees flower and fruit from 2 to 3 years of age. Obviously they are easier to spray, prune, and harvest when trained in the manner of standard-sized trees. On the other hand, such trees tend to heave when shallow-rooted and may be blown over in heavy winds unless protective provisions such as staking are made. Scion rooting is also a hazard and must be prevented by relatively shallow planting, if the dwarfing effect of the rootstock is to continue. With reasonable care, however, such trees may be found quite adequate for home and suburban gardens.

A number of standard apple and pear varieties are available at certain nurseries, some of which list quite a varied assortment. One-year-old whips or 2-year branched trees may be obtained and trained in a manner similar to standard-sized trees. Older trees may be secured from nurseries specializing in the training of trees to the various ornamental types common to Europe. These forms, such as the U-form, fan shape, and single- and double-horizontal cordons must be given some support and will require more continuous attention to training. They also necessitate more care in spraying if grown against a wall, although they are more ornamental than trees trained in the manner of standard-sized trees.

The Quince

The fruit-bearing quince, *Cydonia oblonga*, Mill, may be readily grown on its own roots by propagation from hard-wood cuttings, and by mound-layering. When budded or grafted on a rootstock, the Angers quince (East Malling Type A) is most frequently used.

Quince seedlings are also used as stocks upon which to bud standard commercial quince varieties.

The Peach

As previously indicated peach seedlings are used almost exclusively as rootstocks for the peach. For many years they have been grown largely from seeds collected in North and South Carolina, thus accounting for their name, "Carolina naturals." [69] These seedlings were uniformly vigorous, but the seed has become increasingly scarce and is now a mixture of pits of varying size and nondependable germination. For this reason varieties suitable for seed production, particularly in the commercial class, are in demand.[23] At present an increasing proportion of the seed is taken from standard varieties such as Muir, Lovell, Salwey, and Elberta.[20]

In areas, however, where nematodes are prevalent, peach varieties are found to be most unsatisfactory rootstocks. Seedlings of the almond, apricot, Hortulana plum, Japanese apricot (*Prunus Mume*) and *P. Davidiana*, as well as various plum types, such as Damson, Marianna, Common Plum, Brussels, St. Julien,[41] and Myrobalan, have been tested for specific reactions in respect to compatibility, dry and wet soils, and nematode attacks.[2, 38, 55, 67, 77] All these types of seedlings resulted in pronounced dwarfing and with the exception of Damson and St. Julien, plums have proved to be more or less incompatible with the peach. Furthermore, it was found in England that the various strains of St. Julien were not equally valuable as peach stock.[2]

Recently peach seedlings of the Shalil and Yunnan groups have been found to show marked resistance to nematodes where seedlings of ordinary varieties were heavily infested.[38, 67] Seedlings of the Shalil peach and an understock F.B.I. 61,302 (Bolivian Cling x Quetta nectarine) proved to be completely resistant to the root knot caused by nematodes. Seedlings of the Shalil, Bokhara, and Yunnan peaches have formed a perfect union when used as stocks for standard commercial varieties. They are particularly recommended in regions where nematodes are a serious problem or in the warm, deep sand or sandy loam soil of the Southeastern United States.

The Cherry

Sweet cherry. Seedlings of the wild sweet cherry (*Prunus avium*, L.) known as Mazzard or Bird cherry are most commonly used as seedling stock for the sweet cherry.[5, 17, 36, 41, 69] Although the seedlings show considerable variation in hardiness yet, in general, they result in a stronger, longer-lived tree than is obtainable when the Mahaleb cherry (*P. Mahaleb*) is employed as a rootstock. The latter was used rather extensively in the past due to the fact that the trees were more readily grown in the nursery where they were less susceptible to mildew and leaf spot than Mazzard. They were also more resistant to drought. Experiments, however, have definitely shown that sweet cherry varieties budded or grafted on Mahaleb, although they grew fairly well for a short time, invariably died prematurely or gave evidence of other undesirable characteristics.[5, 14]

Although it is reported in California that Mahaleb is less affected by little-leaf disorder[67] and seemed to be well suited to the hot interior valleys, yet in England the use of this stock was found to predispose the tree to certain diseases such as root rot.[41] Selected strains of Mazzard such as F. 12 have been propagated vegetatively in order to provide more hardy uniform types, but these are not yet available for commercial purposes.

Sour and Duke Cherry. Mahaleb is more commonly used as the rootstock for these cherries. Although it can be readily propagated from root cuttings it is commonly grown from seed. The Mahaleb is generally preferred by nurserymen since its characteristics as a nursery seedling are preferable to those of Mazzard. Recent experiments have shown, however, that Mazzard tends to be equally good, if not actually preferable as a stock for such sour varieties as Montmorency.[5, 14] Although Mahaleb may produce earlier and heavier yields than Mazzard, the trees tend to die earlier and are generally less vigorous. In fact, Mahaleb is used in England in case less vigorous sour cherry trees are required. Furthermore, the Morello cherry budded on Mahaleb died after several years of heavy cropping.

Dwarfing. As a dwarfing stock the Western sand cherry (*Prunus Besseyi*) appears most promising. In the Stockton district of California Morello is used in a limited way for the sweet cherry and will also dwarf other sour cherries. The tree comes into bearing earlier and produces heavy crops, a fact which may be partly responsible for the dwarfing tendency of the stock. The Morello does not form a good union with all varieties.

The Plum

In the United States varieties of the European plum (*Prunus domestica*) are usually budded on the Myrobalan plum (*P. cerasifera*), seed of which is largely imported from France and Italy. Peach seedlings have been used to some extent in the West; they are primarily of value in adapting the plum to lighter soils, since Myrobalan is better suited to the heavier types. In general, Myrobalan produces more vigorous trees than other stocks and even more than certain plum varieties growing on their own roots. Furthermore, because it is cheap and offers a high degree of compatibility with all varieties, it has become the outstanding stock. In England two strains, Myrobalan A and B (selected at East Malling) have undergone extensive tests with the result that type B (propagated vegetatively) has been found to be particularly valuable in the production of vigorous trees.[32]

Several of the plum strains which have been used in Europe as stock for varieties of *Prunus domestica* are of little practical importance in the United States. They are of interest, however, in showing the superiority of Myrobalan over all other stocks in the production of vigorous trees exhibiting no trace of incompatibility.[2, 32]

The Japanese plum (*Prunus Salicina*) grows equally well on both Myrobalan and peach stock. Although the peach has occasionally been used, particularly in the South, and as a means of adapting the plum to lighter soils, the susceptibility of peach seedlings to nematode attack has become a serious limitation. In the South, cuttings of the Marianna plum (presumably a hybrid of Myrobalan and a native plum of the Wild Goose type) are also used occasionally. Marianna seedlings are reported to be resistant to nematode attack. The apricot and almond have proved to be of little value as understocks for the Japanese plums.

Varieties of the native species which are grown in the Central Great Plains area where hardiness is essential, are frequently worked on seedlings of the native plum (*Prunus americana*). De Sota, for example, was found to do well on seedlings of its own species. The Marianna plum is reported to serve as a satisfactory stock for native varieties such as Wayland, Wild Goose, and Pottawattamie, which at present are little grown.

The Apricot

Both apricot and peach seedlings are commonly used as stock for the apricot and have been found compatible with all combinations. The varieties Royal and Blenheim have furnished a considerable proportion of the seedlings. The compatibility of the apricot on peach stocks is interesting in view of the marked incompatibility of the peach when budded upon the apricot. The peach is preferred for early varieties of apricots growing in deep soil in California, but where nematodes are a hazard apricot seedlings are more successful.

The Myrobalan and Marianna plums have been found useful for wet soils, and in the past a considerable number of trees in California were worked upon Myrobalan. This stock has not proved entirely satisfactory, however.

The Western sand cherry (*Prunus Besseyi*) is reported to be preferable for dwarfing the apricot, although St. Julien and Damson plums have been largely used in the past where dwarf trees were propagated.

The Grape

Vinifera grape varieties are grafted on rootstocks immune or resistant to attacks of phylloxera (*Phylloxera vitifoliae*, Fitch) and nematodes (*Heterodera Marioni*) when they are grown in soils badly infested with these organisms. Husmann[37] has tested a number of phylloxera-resistant stocks of which *Vitis riparia* (*V. vulpina*) and *V. rupestris* are not only the most resistant but also the most compatible.

The weaker-growing American varieties Catawba and Delaware may be definitely increased in vigor by grafting upon Clinton (a *V. riparia x labrusca* hybrid).[25] Clinton and Riparia Gloire de Montpelier were also found satisfactory for Campbell Early.

Although the quantity and quality of fruit is improved by means of grafting, the expense is increased to a degree which as yet is commercially prohibitive.

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16

THE ORIGIN AND IMPROVEMENT OF FRUITS

Three centuries of fruit culture in the United States show a constant intensification of interest in the improvement of fruits. And yet it is a relatively small body of men who, with remarkable energy and patience, have selected not merely the progenitors of the recent varieties, but in some cases, varieties still commercially important.

Perhaps one of the most fascinating aspects of fruit breeding is the element of chance which is constantly involved. At present the majority of the acreage of practically all fruits is composed of varieties which were chance seedlings. Either they have been brought in from the wild, and propagated asexually thereafter, or else they have developed from seeds sown by some imaginative grower. As time passed the number of controlled crosses made by private breeders has constantly increased.

Within the last 25 years a small but growing percentage of the fruit acreage has been devoted to varieties developed from breeding projects of public agencies. Alderman [1] has listed 541 fruit varieties so originated, many of which have not had sufficient trial to permit conclusions as to their value. Over 50 varieties have become established or have shown considerable promise. Fifty others were classified as of "significant horticultural value." In the improvement of the well-known, as well as the more unusual fruits, lies the possibility of the greatest advancement in pomology in this century. Progress must be attempted not only in the achievement of higher dessert value, and more satisfactory preserving and shipping qualities, but in the development of varieties more resistant to disease and insect pests. In fact some observers believe the latter field offers the most promising opportunities. To accomplish this purpose a well-planned breeding program carried out over a considerable period of time is essential.

The Apple

The cultivated apple, *Malus sylvestris* (*M. communis*), Mill, is believed to have had its original habitat in the mountain ranges of the Caucasus extending between the Black and Caspian Seas. Vavilov,[41] Director of the Institute of Plant Industry of the Union of Soviet Socialist Republics, has presented a valuable study of the wild progenitors of fruit trees in that region. He writes, "On the northern slope of the Caucasus, there are vast woods consisting of the wild progenitors of fruit trees. . . . The principal center where the species and forms of the majority of the wild progenitors in the Caucasus have originated must be sought in Transcaucasia and the adjoining regions of Asia Minor and Persia."

Today in the Caucasus there is, according to Vavilov, extraordinary diversity in the forms of the wild apple, with fruits differing in color, shape, and flavor, but usually small in size. In Turkestan the wild apples are comparatively large and it is there, writes Vavilov that "the whole scale of transition from the typical, small, sour apples to the cultivated perfectly edible forms may be observed."

The improvement of the apple has, from the beginning, consisted largely of the selection of chance seedlings, a procedure followed even today among the inhabitants of Turkestan and the Caucasus. Cato (234–149 B.C.) is reported to have known 7 varieties and Pliny (1st century A.D.) 36 kinds. The number in Europe had grown to several hundred shortly after the colonization of America began, and for many years, seeds of European varieties were brought to America for planting.

Here dissemination of the apple was very rapid due to the activities, not only of the colonists, but of the Indians also. Literally thousands of seedlings were grown in the area extending from the New England states to Virginia, and westward to the Mississippi Valley. Seedling orchards became quite common around the homes of settlers, and in the vicinity of Indian villages. From the great numbers of seedlings and their progeny all the known apple varieties have been selected.

The development and improvement of the apple in this country was advanced by men of immense foresight. William Coxe, called by Fletcher[22] "the pioneer pomologist in America" had what is assumed to be the first experimental orchard. He secured varieties of fruits from Europe, and from the various states here, and introduced many new ones. Of the apple alone, he offered 80 varieties for sale in 1804.

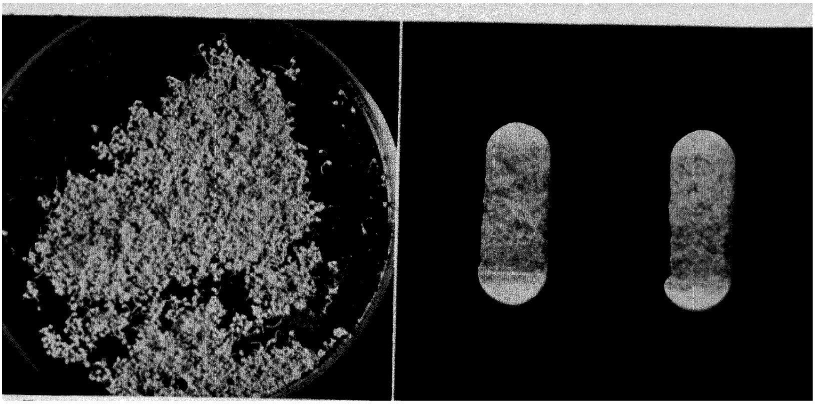
Two men whose contributions to fruit culture were invaluable were Benjamin Franklin (1706–90) and John Bartram (1699–1777). Franklin initiated the first apple export trade, and Bartram founded the first botanic garden in America, which served as a clearing house for the exchange of both foreign and domestic fruit plants.

After 1800 when grafting became more generally known and practiced, the number of named varieties increased rapidly. During the nineteenth century, Hedrick and Wellington [28] state that 3,000 or more apple varieties were described, most of which are now unknown. Beach [6] described 698 varieties in *The Apples of New York*, the now classical compendium of varieties of which the origin of 517 is unknown.

Within recent years varieties introduced have in several instances been chance seedlings such as Golden Delicious, but more commonly they have originated as gene mutations (so-called "bud sports") of standard varieties. A number of apple varieties have also been introduced as a result of controlled breeding, of which Cortland is possibly the outstanding example. Magness has presented an excellent review of the origin and improvement of the apple to which students are referred.[33]

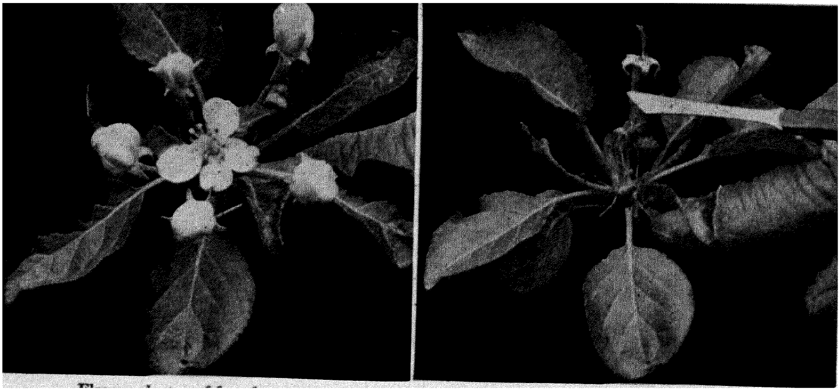
Breeding work at various experiment stations. Apple breeding has been a major project in Iowa, Minnesota, New York, and South Dakota and has been given some attention at other stations also. (Figs. 83, 84.)

Production of new apple varieties by breeding is retarded by several factors. In the first place, knowledge of the inheritance of characters is incomplete, and the exact genetic composition of the parents is unknown. Secondly, the impossibility of obtaining progeny from self-pollinating varieties has delayed segregation of distinct types, since crosses must be made between seedlings and varieties which are, in most cases, extremely heterozygous. In the third place, 5 to 12 years must elapse between the time when the cross is made and the production of fruit by the seedlings resulting therefrom. Finally, cytological irregularities in the development of the sex cells of certain varieties, otherwise valuable, limit the number of desirable parents. For example, the triploid varieties which invariably consist of large, vigorous trees and large fruits cannot be used as either parent.



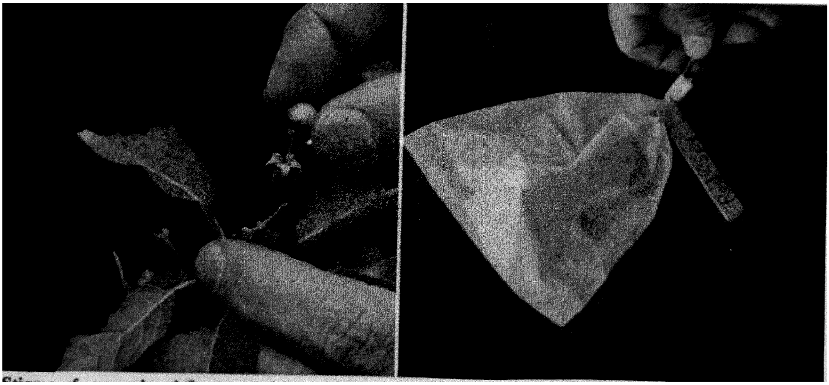
Dried anthers collected from male parent

Anthers in gelatine capsule



Flower cluster of female parent

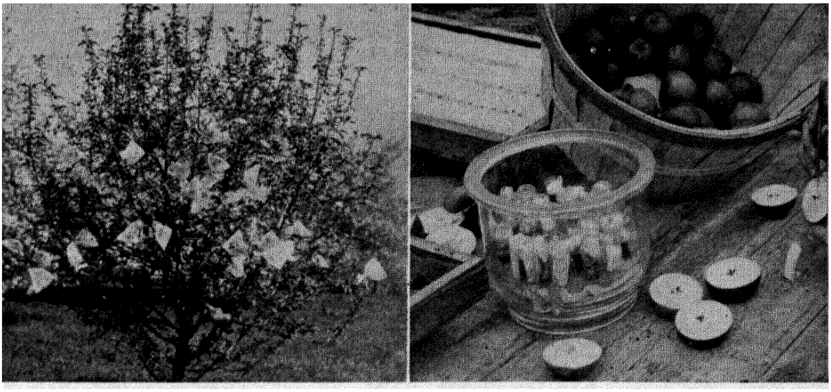
Two flowers emasculated (anthers removed), other flowers discarded



Stigma of emasculated flower receiving pollen from capsule

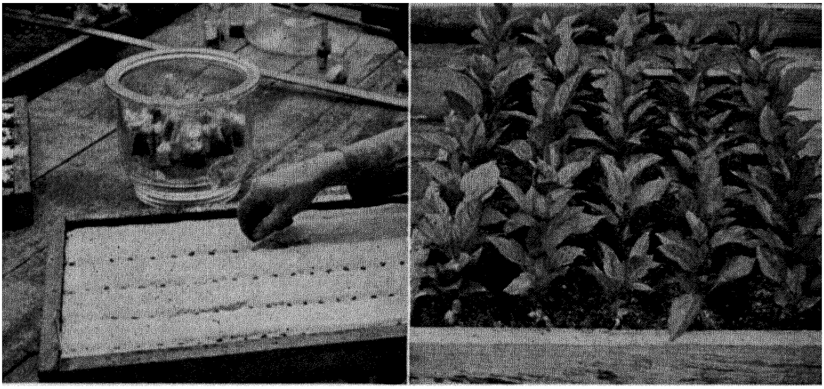
Flowers covered with glassine bag

FIG. 83. The breeding of a new apple variety.



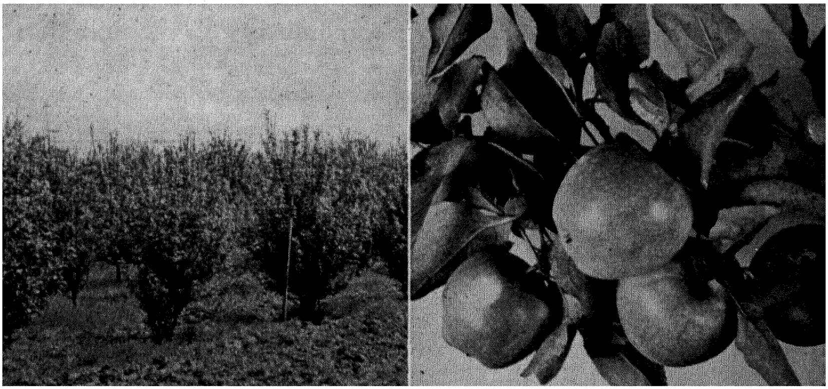
Female parent tree with numerous glassine bags

Seeds from fruits of this tree placed in bottles—also kept in refrigerator until sown



Seed being sown in flats in greenhouse in March

Seedlings later in the spring just before planting out



Seedling trees several years later

Fruit of one of these seedlings—the new variety

FIG. 84. Breeding of a new apple variety (*continued*).

Crab-apple. The term "crab-apple" is usually applied to varieties developed from crosses of the Siberian Crab (*Malus baccata*) and the common apple. For example, Transcendent, Hyslop, Whitney, and Excelsior (the latter two closely resemble the cultivated apple) are presumably the offspring of *Malus baccata* and some unknown, standard, large-fruited apple variety. However, the term may be equally applied to various crab species such as *Malus Sieboldii* (Toringo crab-apple) and *Malus baccata* itself.

The Siberian Crab, a native of Siberia and China is the most widely known crab species in the United States. It is characterized by small fruits, yellow or red in color, with deciduous calyx. The trees are large, very hardy, but extremely susceptible to fire blight. Not only has the species been used in breeding hardy varieties for northern regions of the United States and for Canada, but seedlings within recent years have been used as stocks for cultivated standard varieties. The botanical variety, *mandshurica* possesses slightly larger fruits, and seedlings of this type are preferred to *baccata* because they are more uniformly vigorous and of equal hardiness.

Other species of crab, such as *Malus ioensis*, Brit. (Prairie crab-apple) are native, but of little importance in pomology. Still other species, such as *Malus Sargentii*, Rehd. and *Malus Sieboldii*, Rehd., native to Japan, are used entirely for ornamental purposes.

The Pear

Wild pear trees are found growing abundantly in the Caucasus, and in Turkestan, along with the wild apple.[41] This locality appears also to be the native habitat of the progenitors of the European pear, *Pyrus communis*, L., which comprises all the well-known European varieties.

The pear was cultivated in Europe long before the Christian era. Theophrastus (370–286 B.C.) mentioned both wild and cultivated varieties, while Pliny later gave the names of over 40. Pear culture spread through Europe, with interest culminating in the 18th century in Belgium and France. Hardenpont (1705–74) introduced a number of varieties and Van Mons (1765–1842), who was a physician and pharmacist, and at the same time, greatly interested in the improvement of fruits, particularly the pear, developed pear breeding on a tremendous scale, and at one time had 80,000 seedlings. He originated Beurré Bosc and Beurré Diel. The 19th century marked the high point of pear breeding.

Pear varieties were brought to this country by the colonists. In contrast with the apple, nearly all our present commercial varieties are of European origin. The Bartlett which is known in Europe as Williams' Bon Chrêtien was raised by seed in England in 1770. Other varieties such as Beurré Bosc and Beurré d'Anjou were brought, either as trees or scions, to the United States. Forty-two varieties were tested in Prince's nursery in 1771. Coxe offered 90 kinds for sale in 1804. In his book [12] (1817) the only varieties that are now recognized are Bartlett and Seckel, the latter having originated near Philadelphia.

Another species of pear, which has been involved in the production of several American varieties, is the Sand Pear, *Pyrus serotina*, Rehd. (*Pyrus pyrifolia*, Bailey) which has its native habitat in China. This species is characterized by large vigorous trees, relatively resistant to blight. The fruits possess a deciduous calyx and a pronounced depression around the stem, as in the apple, which they closely resemble in form. They are also very hard, brown, crisp, possess many grit cells, and are very inferior in dessert quality. This species hybridizes freely with the European pear varieties, and Kieffer is presumably one of its hybrids with Bartlett. Le Conte, Garber, Douglas, and Pineapple are also hybrids of this species and the European pear, and are likewise very inferior in quality as compared with the better European sorts.

Other species of the oriental type, introduced from Asia where they are native, have been used experimentally as stocks for European varieties, but are, as yet, of only a limited significance in the United States. They are:

Pyrus ussuriensis, Maxim. Ussurian pear
This species is very hardy and blight resistant. For this reason it has been tested experimentally as a stock for the European varieties, but has proven unsatisfactory because of the black-end disorder which has developed on fruits of these varieties worked on this stock. The wild type has produced a higher percentage of resistant seedlings than any other species.[87]

Pyrus Calleryana, Decne.
This species has shown greater resistance to fire blight in the trunks and roots than any other species used by Reimer in Oregon for rootstocks. It is, however, less hardy than *P. ussuriensis*.

Pyrus betulaefolia, Bunge
This species is in general less resistant to blight than the two above mentioned. It is at present on trial as a stock for European varieties and it is not yet known to what extent trees on this species will exhibit black-end. The species

withstands more alkali in the soil than others, propagates readily from root cuttings, and is reported to be well adapted to sandy or gravel soils.

Another European species, *Pyrus nivalis*, Jacq., called the Snow or Perry pear, is of limited importance in Europe, where it is used for making "perry," a fermented pear juice.

An excellent review of the origin and improvement of the pear has been presented by Magness in the *1937 Yearbook of the United States Department of Agriculture.*[34]

Improvement by breeding in the United States. Pear breeding has been carried out by the United States Department of Agriculture and by several experiment stations. The primary objective has been to obtain high quality varieties more resistant to blight than the majority of European varieties now known. Of the present leading varieties of European parentage only Seckel shows a high degree of blight resistance. These highly desirable objectives of pear breeding have not as yet been successfully fulfilled.

The Quince

The common quince, *Cydonia oblonga*, L., Mill, is a native of Asia, and is grown in temperate climates for the fruit which is useful only for preserves and culinary purposes. The quince is also grown, although in a limited way, as a rootstock for dwarfing pear trees. In wood, it is not much hardier than the peach, being severely injured at 15 to 20 degrees below zero. It is a slow-growing, shallow-rooted tree, requiring a rather moist, deep soil for best results. The quince is exceedingly susceptible to infection by fire blight (*Bacillus amylovorus*) and to attacks of the oriental fruit moth (*Laspeyresia molesta*). In some localities, fruits free from injury by this insect can be produced only by enclosing them in cheesecloth bags. Commercial quince culture is largely restricted to California, New York, and Ontario. Some regions of the world have produced varieties of higher quality than those grown here where the one outstanding variety is Orange, noted for its earliness, color, and quality. Other varieties sometimes grown are Champion, Meech, Fuller, and Smyrna.[5]

The Peach

The peach (*Prunus Persica*, Sieb. Zucc., or *Amgydalus Persica*) appears to have been known first in China, where, like the apple in Europe, it became associated with the artistic and folk legends of the country.[10] According to Bretschneider, it was first mentioned in Chinese literature in 551 B.C. From China its cultivation travelled westward to Persia, and from this locality it became known to the Romans as the Persian apple, *Malus persica.* The Roman writers, Columella and Pliny have referred to the peach, although it was not mentioned by the earlier agricultural writers, Cato (234–149 B.C.) and Varro (116–28 B.C.). In Pliny's time (first century A.D.) several varieties were known and it is thought that nectarines also were familiar. From Rome, cultivation spread through Southern Europe, reaching England in the Anglo-Saxon period. According to present evidence it is believed that peach cultivation was continued in Europe without interruption from the Roman Period on, while the number of varieties gradually increased. From the beginning of 1600 and continuing for at least two centuries, the greatest improvement took place in France, where the number of varieties was multiplied several times.

The peach was first introduced into the United States by the Spanish colonists who settled at St. Augustine in the 16th century. Very quickly thereafter the seed was disseminated both northward and westward by the Indians and by the time the English colonists landed in Virginia the peach was growing wild as far north as Philadelphia, giving rise to the opinion, held for some time, that the fruit was native to this country. For nearly two centuries thereafter the peach was grown chiefly as an adjunct to the fruit plantation and it was not until early in the 19th century that commercial peach growing was undertaken, although previous to that time thousands of trees had been planted.

From 1850 to 1890 a large number of varieties were selected from seedlings as worthy of propagation. This includes some that are still grown commercially, as well as several which are the parents of varieties introduced within the last 20 years. The Elberta is reported to have been grown in 1870 from seed of the Chinese Cling, a type which was imported by the horticulturist Charles Downing from Shanghai, China, in 1850. The Chinese Cling is a representative of the North China or Chinese Cling race which is characterized by vigorous tree growth, tender fruit flesh, and abundant and regular bearing. This group is represented by the Elberta and Belle of Georgia varieties. Varieties have been developed since that time which have higher dessert quality and greater tree and bud hardiness, but considering all factors, Elberta is still standard over the entire country, being more widely adaptable than any other yet produced.

Within the last few years a number of varieties have been introduced by private agencies and are receiving extensive trial. Students are referred to Cullinan's discussion of the origin and improvement of the peach.[14]

Peach breeding. Within the last 25 years breeding has been initiated at several experiment stations to secure varieties better suited to local conditions. The general purpose is to obtain varieties more hardy in wood and bud, and higher in dessert quality than Elberta.

The Cherry

Transcaucasia and the adjoining regions of Asia Minor and Persia are considered to be the native habitat of the sweet cherry (*Prunus avium*, L.). Vavilov [41] reported the principal centers of varietal diversity to exist in this region,—a diversity extending from the typical wild forms to the larger types found among the native cultivated varieties. The earliest reported cultivation occurred in Greece. Theophrastus described the sweet cherry about 300 B.C. but, as is the case with other fruits, cultivation was presumably initiated prior to the earliest written accounts.

The sour cherry (*Prunus Cerasus*, L.) is supposed to have appeared in the same region as the sweet cherry. DeCandolle suggested that this species developed from the sweet cherry. In view of the fact that the sour cherry is polyploid (4x), with double the chromosome number of the sweet cherry (2x), his suggestion has an interesting significance, since species or types possessing chromosome numbers which are a multiple of three or more times the basic gametic number presumably have their evolutionary background in the simplest type.

It is also believed that man has been practically the sole agent in the continental distribution of the sour cherry. Pliny is credited with the account of the first cherry described in Italy, but it was not until the 16th century that cultivated cherries were again described in full.

The colonists brought the cherry to America, most of the varieties imported having come from England. Modern cherry growing on the Pacific Coast began in Oregon, where the Lewelling Brothers originated several sweet cherry varieties. Of these Republican, Bing, and Lambert, developed as seedlings of Napoleon, are still predominantly cultivated in the Northwest. The varieties Black Hawk, Kirtland, and Rockport (soft-fleshed types) were introduced by Kirtland (1793–1877) near Cleveland, Ohio. Kirtland gave particular attention to breeding pears, cherries, grapes, and raspberries. Hedrick and associates [26] report that 30 varieties of sweet cherries originated by him are described in *The Cherries of New York* of which Wood (Governor Wood) is the most prominent.

The Duke cherries are hybrids of the sweet and sour cherry. In general, the Duke varieties resemble the sweet more than the sour, differing from the former principally in the increased acidity of the fruit juice. Presumably the Dukes originated from the fertilization of a *diploid* egg nucleus ($2x$) of the sweet cherry by a normal haploid male gamete ($2x$) of the sour cherry. This would account for the greater resemblance of the Duke varieties to the sweet cherry, although they are tetraploid ($4x$) as is the sour cherry. The Duke varieties show a high percentage of pollen sterility, and the egg nuclei are also more or less unstable, thereby resulting in only fair productivity as compared with either the sweet or sour cherry.

The Mazzard is the name given to the wild sweet cherry (*Prunus avium*, L.). The trees reach a height of thirty to forty feet and the fruits are usually smaller than those of cultivated varieties and dark in color. The Mazzard seedlings used commercially are grown from seed obtained from these trees.

There are a number of other cherry species but few are of pomological importance. Among the better known are:

Prunus Mahaleb, L. (Mahaleb or St. Lucie Cherry)

This species is cultivated as an ornamental and as a stock for both sweet and sour cherries. It is of Eurasian origin.

Prunus Besseyi, Bailey (Sand Cherry)

This species has been used for breeding, for dwarfing various stone fruits, and as a hardy understock. It is native to central North America.

The Plum

The plum includes several species whose native habitats are widely separated. The most important species is *Prunus domestica*, L. It was presumably from the area between the Black and Caspian Seas and the adjoining regions of Persia and Asia Minor that this species spread westward. Apparently it was not domesticated as early as other fruits.

According to the earliest records in which this plum is mentioned, the species dates back over 2,000 years. The *insititia* or damson group is reported to antedate *Prunus domestica,* as is suggested by the discovery of damson pits in ancient ruins. The earliest writings associate the early culture of these plums with the region around Damascus, from which the term "damson" is presumed to have originated. Plums were not known in Italy much before the beginning of the Christian era.

Crane at the John Innes Horticultural Institution, England, advanced the hypothesis that the cultivated plum originated, in reality, as a hybrid of the two wild species, *Prunus spinosa,* L. (European sloe) and *Prunus cerasifera,* Ehrh., the common Myrobalan plum.[13] Russian plant explorers are now reported to have verified this hypothesis by their discovery, in the North Caucasus, of natural hybrids of these two species which are very similar to the European plum in a number of important tree and fruit characters.[32] In fact, Rybin obtained fertile hybrids of these two species, one of which had the same chromosome number as the European plum (6*x*), despite the fact that the ordinary, natural hybrid should have but 24 chromosomes.

The European plum is known to have been introduced into Massachusetts shortly after the establishment of the colony. Plum trees were not common in colonial orchards, but by 1828 the Prince nursery offered 128 varieties for sale. A number of these at least were originated by planting the seeds of Green Gage plums, representative of the Reine Claude group, possibly one of the earliest to be domesticated from the wild.

Formerly the *insititia* plums were considered to be a separate species but Bailey classifies them as *Prunus domestica,* var. *insititia.* This subspecies is considered to include 4 groups, the Damson, Bullace, Mirabelle, and St. Julien plums. The Damson and Bullace plums are not readily distinguishable and Hedrick concluded that there is little justification for subdividing *insititia* into more than 2 groups.

The Japanese plum (*Prunus Salicina,* Lindl.), was domesticated in Japan and was introduced into the United States about 1870 by Luther Burbank. He produced from them many seedlings and hybrids, such as Burbank, which are widely grown.

The native American plums are assumed to have been used as food by the Indians. Dissatisfied with the quality of these native species, the colonists imported plum seeds and varieties from Europe.

The cultivated varieties of more than a dozen native species are found in American orchards or growing in the wild, but the following species are the most important:

Prunus americana, Marsh. Small native plum
The species is resistant to low temperature.
Varieties: DeSota, Hawkeye, New Ulm, Rollingstone, Weaver, and Wyant.

Prunus Munsoniana, Wight and Hedr. Wild Goose plum
The species is resistant to high temperature.
(The Soil Erosion Service is growing millions for distribution to sites where erosion is a factor.)
Varieties: Downing and Wild Goose.

Prunus hortulana, Bailey. Hortulan plum
This species is also resistant to high temperatures. The outstanding variety is Wayland.
Var. *Mineri:* Miner

Prunus nigra, Ait (*Prunus americana*, var. *nigra*) Canada plum
The species is resistant to low temperature.
Variety: Cheney.

A species of minor importance which has been introduced from China is *Prunus Simonii*, Carrière, the Apricot plum. This fruit has been used in breeding with the native species as well as with the Japanese plum to produce such varieties as Shiro and Wickson (Luther Burbank).

These species are diploid with 16 chromosomes. They have served as progenitors of hardy native plum varieties, and several have recently been used in breeding with the Japanese and other oriental types. In the states of the Upper Mississippi Valley the plums grown are largely hybrids of *Prunus Salicina* and *Prunus Simonii*, combined with the native species, *Prunus americana*, *P. nigra*, *P. Besseyi*, and *P. hortulana*.

Another minor species is:

Prunus cerasifera, Ehrh. Myrobalan or cherry plum
This species is found in the wild forests of the Caucasus and Turkestan. It is widely used as a stock for the plum and other stone fruits.

The Apricot

The apricot varieties of commercial importance in the United States belong to the species, *Prunus Armeniaca*, L. As was the case with the peach, the apricot was named for the region of its supposed origin (Armenia), but it is now believed that it too originated in China. It is interesting to note in this connection that Vavilov [41] reported that forests of wild apricot trees in Turkestan are comprised of many forms, some edible, differing only from cultivated varieties in that they have smaller fruits and stones. The apricot early reached southeastern Europe and was mentioned by Pliny and Dioscorides in their writings.

The first apricots imported to America were brought to California from Spain by the early Mission Fathers in the 18th century. No mention is made of the fruit until early in that century (1720) in Virginia, where it was reported to be grown rather extensively. As with the pear, the greater number of varieties grown in America are of European origin. A number of strains or varieties have been originated, as might be expected, in California where they are most extensively grown. These are: Alameda, Hemskirke, Routier Peach, Derby, Royal, Spark's Mammoth, Stewart, and Wiggins Seedling (Wiggin). Other varieties of more recent origin are Wenatchee Moorpark (possibly identical with Moorpark), Riland, Gilbert, and Sofia. The Royal and Blenheim, both of English origin, together with Tilton (of American origin), comprise the greater part of the present apricot acreage in California. As indicated above, several strains have been selected which are assumed to be better suited to the climate and soil conditions of the localities in which they are grown.

Two types are considered by some authorities as species, but Bailey classifies them as forms of the common apricot, namely, the Russian apricot (*Prunus Armeniaca*, var. *sibirica*, L.) and the Manchurian apricot (*Prunus Armeniaca*, var. *mandshurica*, Koehne). These are commonly found in the Far East, but both are of interest only to the breeder as possible sources of hardy apricots.

Results of breeding. A new emphasis upon apricot breeding has recently been observed, particularly since it has been found desirable to obtain a later-blooming, hardier type. In the past, attainment of this objective has been hampered by lack of parents possessing the desired characteristics. The strains of Russian and Manchurian apricot are hardier in bud, and later blooming, but the fruits are of small size and poor quality.

The apricot was crossed with plum varieties, particularly the Japanese plum, by Luther Burbank. The group name, Plumcot, has been given to seedlings produced. The more important varieties are Apex, Corona, Rutland, Silver, and Triumph. They are little grown as yet.

The Grape

Presumably the grape was first introduced into cultivation at the time of the development of wine making in the regions of the ancient Eastern civilizations. According to Vavilov [41] "Transcaucasia is the principal center whence the forms of the wild and cultivated grape have originated. These grapes have been cultivated and used for thousands of years." The grape spread westward with the advance of civilization; varieties were brought from the Caucasus and Asia Minor to Greece and later to Italy. In some instances they were crossed with local, wild forms and the progeny presumably introduced into cultivation, as a result of which, each region showed a tendency to develop its own native assortment.[36]

The species of European grape (*Vitis vinifera*, L.) comprises one of the most ancient forms and, as a result of extensive culture in many regions, it is now very polymorphic, possessing over 3,000 varieties, which are extremely diverse in morphological characters. Negrul states [35] that the American and Old World species, though separated many thousands of years ago, are genetically still remarkably close, and crosses between them are very little different from crosses within *Vitis vinifera* since they have many characters in common. Within nearly every character, however, the extremes of expression are encountered in *V. vinifera.* In this connection Negrul writes further, "This greater variation is the result of centuries of cultivation, unconscious or conscious selection of bud mutants, and in more recent times hybridization, partly occurring naturally among escaped populations growing wild (Central Asia) and partly artificial. In spite of this great polymorphism, the author is not of the opinion that the species *V. vinifera* is a collective species which can be split up into a number of separate species, as has been done by some investigators. The wild vines of Central Asia are definitely thought to be escapes and not a true wild species, and vine cultivation is thought to have had its origin in Transcaucasia, North Iran, and Asia Minor, some form resembling the present subspecies *silvestris* having been taken into cultivation. The juicy, wine varieties are thought to be the oldest type; seedless forms originated much later as a bud mutation, their persistence being only possible under vegetative reproduction. Still later apparently were the muscats, which also seem to have arisen as bud mutations. The fleshy table varieties are also the product of artificial selection. The three latter types all seem to have originated in Iran and they are certainly absent in the escaped wild populations of Tian-Shan, Darvaz, and also in Daghestan, and western and eastern Georgia." [35]

In view of the fact that the grape industry in Europe has always been centered around *Vitis vinifera*, it was this species which was brought very early to Virginia (1619). Its introduction, however, was a complete failure throughout the colonies from New England to Georgia. This outcome was due apparently to a lack of resistance to low temperature in the north, and to the attacks of diseases and insects in the south. Finally, attempts to grow European varieties were abandoned (1850) when it became evident that seedlings of the native species, crossed with Vinifera varieties, offered the best solution of the problem.

The Alexander grape was the earliest variety selected. The Catawba following somewhat later (1823) is presumed to be a hybrid of *Vitis vinifera* and *V. labrusca*, L. (Fox grape) although like many other varieties its exact origin is unknown. This variety together with Isabella (1816), of supposedly similar parentage, occupied the field, until Concord, also a chance seedling, fruited in 1849.

In regard to the origin of American varieties, Bailey [4] concluded that "the parentage of many well-known American varieties is speculative or opinional." Thus it is considered that the greater number of these varieties have originated as hybrids of these species and *Vitis vinifera* or as seedlings of such hybrids.

The grape industry in the United States is now centered about two main lines of inheritance, but *Vitis vinifera* is an important factor in both. On the West Coast the development has been confined largely to varieties of pure Vinifera. In the remainder of the country, grape culture, Bailey [4] declared, "is the outcome of domestication of the native species of Vitis within about a century." He also stated that the only native species which have contributed to viticulture on this continent are *Vitis labrusca*, *V. aestivalis*, and *V. vulpina* (*V. riparia*). The effect of *V. vinifera* in introducing quality into American grapes has been of inestimable value. In fact, present attempts to produce more excellent table varieties than those now available, involves the addition of still more Vinifera inheritance without loss of the resistance to disease and the hardiness contributed by native varieties.

It is interesting to note that the native species such as *Vitis labrusca* and *Vitis rotundifolia*, Michx (Muscadine grape), which were introduced to cultivation only about 150–200 years ago, are considerably less polymorphic than *Vitis vinifera* and are beginning to accumulate the variations which the European species already possess.[86]

Muscadine grapes. The muscadine grape (*Vitis rotundifolia*, Michx) is a native of the southeastern portion of the United States. A representative of this species was first cultivated in the form of the variety Scuppernong, which is reported to have become definitely established in Tyrell county, North Carolina, before 1760. In this section of the state many large vines are known to be over 100 or 125 years old. The varieties Mish, James, Flowers, and Thomas were all chance seedlings discovered during the period from 1819 to 1867 in either North or South Carolina. These varieties along with others are adapted to the local requirements for fresh fruit in the Coastal plain region from southern Virginia to Texas.

The Strawberry

The cultivated strawberry varieties of the United States have been largely, if not entirely, developed from two species, *Fragaria virginiana*, Duch. and *Fragaria chiloensis*, L. Duch. The former is known as the wild meadow, or Virginian strawberry of Eastern North America and the latter as the Chilean strawberry, found along the coast of Chile in South America, and from Alaska to California on the Pacific Coast. The hybridization of these two species from which our modern cultivated varieties developed, occurred in Europe in the 18th century, but relatively little attention was paid to the adaptation of these species to strawberry culture until a century later.

The history and development of the strawberry is exceptionally interesting.[9, 19] Since the time of Pliny, a species native to Europe, known as *Fragaria vesca*, L., had been familiar to horticultural writers. It is not thought to have become a cultivated plant there until the 15th century, although it was frequently mentioned by the herbalists and was known in gardens before that time, particularly in the French gardens during the 14th century. This species also includes the races known as the Alpine, Perpetual or Everbearing types (var. *semperflorens*). The Alpine strawberries of which there are both red and white forms first appeared in the European fruit gardens in the 18th century but never were widely popular. Recently, however, seedhouses in the United States have been offering seeds of a runnerless type of Alpine strawberry which has been grown in kitchen gardens in France since at least the early part of the 19th century.

The history of the modern strawberry is considered to date from the early 17th century (possibly 1624), the introduction of *Fragaria virginiana* into Europe having taken place at about that time. The bright color and good size of the fruit led to its extended cultivation, but it is reported that few variations appeared after over a century of cultivation. Seeds were reimported from North America to England but these too showed no more variation than might be expected from the wild type. The species failed to produce varieties of outstanding size or any remarkable qualities. However, the introduction of the Chilean strawberry, *F. chiloensis* furnished the required size and in combination with the Virginian strawberry laid the foundation for the large-sized fruits known today. *Fragaria chiloensis* was introduced into France by a French officer named Frezier. Only five plants survived the long journey from Chile to France and *one* of these became the parent of a large strawberry industry near Brest, France. The first plants were pistillate and no fruit was produced until a few years later when Duchesne succeeded in fertilizing a plant with pollen of another European strawberry, the Hautbois, *Fragaria moschata*, Duch. (*F. elatior*). The fruits of this species are small and of excellent flavor, but the plants are not sufficiently productive.

The next chapter of the history of modern strawberry varieties was written in England where plants of *Fragaria virginiana* and *F. chiloensis* were imported and grown side by side.

The varieties originated in Europe were soon introduced into the United States and many of them were grown extensively, particularly previous to 1850. Darrow reports that commercial strawberry growing began near the larger cities in the United States about 1850 with varieties which are no longer cultivated. About 1851 beginning with the variety Wilson, there began the introduction of a succession of varieties whose qualities permitted extension of strawberry culture over a wide portion of the United States. These varieties were largely originated by private breeders, although the plantings developed by public agencies are gradually increasing. In 1937 Darrow estimated that the latter amounted to only 10 per cent of the acreage. In his summary of strawberry improvement Darrow listed the 20 most important varieties grown in this country.[19] The most important of these varieties in order of decreasing acreage are Klondike (30 per cent of the total acreage); Premier (Howard 17) (16 per cent); Aroma (10 per cent); Blakemore (8 per cent); Missionary (7 per cent); Marshall (7 per cent); Dunlap (3.5 per cent); Chesapeake (2 per cent); Joe (2 per cent); and Dorsett (2 per cent). Of these 20, 4 were chance seedlings, namely: Missionary, Marshall, Chesapeake, and Parsons Beauty (Pocomoke). Twelve were originated by private breeders and 3 by public agencies. In addition to those considered as the first 20, Ettersburg No. 121, Howard Supreme, Rockhill, Progressive, Aberdeen, Mastodon, and Beaver are varieties which were originated by private breeders.

It is interesting to note the chromosome number of the various species of strawberry since complex polyploidy exists in this genus. *Fragaria vesca*, including the Alpine type, is diploid ($2x$) with 14 chromosomes, while the 2 species, *Fragaria virginiana* and *F. chiloensis* are octoploid ($8x$) with 56. On the other hand the Hautbois strawberry *Fragaria moschata* is hexaploid ($6x$) with 42 chromosomes. As would be expected the modern cultivated varieties are also octoploid, a fact which indicates the possibility of considerable variation in breeding.

The Raspberry

The cultivated raspberries of North America fall into four groups as follows:

1. *Rubus idaeus* var. *strigosus*, Michx.
   Common or American red raspberry. Source of the common named red varieties, several of which are yellow-fruited.
2. *Rubus occidentalis*, L.
   Black raspberry, Blackcap. The best-known variety is Cumberland.
3. Hybrids of the red and black raspberries. Varieties: Columbian, Potomac, and Sodus
4. *Rubus idaeus*, L. European raspberry
   Varieties: Lloyd George and Pynes Royal

Red raspberry. The first red raspberries were cultivated in Europe about 400 years ago. Several varieties were introduced into the United States before 1800 and were extensively cultivated. The variety Red Antwerp was one of the best known in 1806. Finally selections of the native American red raspberry came into cultivation. Dr. Brinkle, a leader in pomology between 1825 and 1863, did pioneer work in breeding this fruit. The Orange raspberry introduced by him in 1845 was long a standard commercial variety. The Cuthbert, discovered about 1865, is thought to be a hybrid of a European variety, possibly Hudson River Antwerp, and a wild native red. This variety and Ranere (St. Regis) according to Darrow [17] are the only important red raspberry varieties, originating as chance seedlings which are now grown. Latham, Chief, Ohta, Marlboro, Indian Summer, King, June, and Newburgh have been originated by private breeders or public agencies. Marlboro was for many years the leading variety and is grown even yet to some extent in Western Washington.

Black raspberry. The Ohio Everbearing, discovered by Nicholas Longworth of Cincinnati in 1832, is considered to be the first named black raspberry. This berry did not become popular until relatively late, because the only known method of propagating the fruit was quite difficult. The introduction of the Doolittle variety in 1850 was a definite milestone, for at this time it became known that the black raspberry could be propagated by tip-layering.

The Gregg variety, introduced in 1866, was a chance seedling and for many years was the standard variety in the Midwest. Due to the fact that it was susceptible to disease, not sufficiently hardy nor well adapted to various soil types, it is now seldom grown. The Cumberland, introduced in 1896 has been the best known and most widely distributed black raspberry. Its chief assets are hardiness and productivity, although it has lost some popularity due to susceptibility to anthracnose.

Purple raspberry. The principal purple raspberry varieties are selected seedlings, the most important being Columbian, a seedling of Cuthbert. All stocks of this variety are now considered by plant pathologists to be infected with mosaic. Sodus and Potomac are recent introductions which seem promising.

The Blackberry and Dewberry

The blackberry came into cultivation early in the 19th century in this country, practically all varieties having been selected from the wild species. There is no agreement among authorities as to the number and names of the species which have contributed to the inheritance of our present varieties. Hybridization has occurred for several hundred years and considerable disagreement has arisen as to the extent and importance of this factor in a number of cases. Brainerd and Peiterson [8] and Bailey [3] have presented monographs on *Rubus*.

Bailey's classification will be followed in this text although it is understood that this does not necessarily exclude other authorities.

I. Ursini. Pacific Berries

Rubus macropetalus—varieties: Aughinbaugh, Belle of Washington, Cazadero, Humboldt, Skagit Chief, and Washington Climbing.

Rubus loganobaccus—varieties: Loganberry and Phenomenal dewberry.

Rubus titanus—varieties: Mammoth blackberry or "Black loganberry" and Cory Thornless (mutation of Mammoth).

II. Triviales. The Southern Dewberries

Rubus trivialis—varieties: Bauer, Drishill, Eight Ells, Extra, Houston, Howard, Lime Kiln, Long Branch, Lost Ball, McDonald (of some), Manatee, Muchee Grandee, Race Track, Rock Ledge, Rogers, San Jacinto, White, and Wilson. Nessberry is recorded as the result of a cross between *Rubus rubrisetus* and Brilliant red raspberry (*Rubus idaeus*, var. *strigosus*).

Rubus trivialis is considered by Bailey to be the major species including Rydberg's *Rubus rubrisetus*. *Rubus mirus* possibly includes the Marvel dewberry or blackberry grown in Florida. It has also been known as Ballough-berry and Australian blackberry. Bailey states it may belong to *Rubus trivialis*.

III. Procumbentes. Dewberries

Rubus flagellaris—var. *geophilus*, Bailey includes Mayes (Austin) and Geer dewberries; var. *almus* includes Foster Thornless, Lucretia, and Gardena.

Rubus velox—varieties: McDonald dewberry, Spaulding, perhaps also but less typically, Sorsley, Sonderegger, Haupt, Hoco, Texas Early, Soft Core, Jordan, Dallas, and Texas Everbearing.

VIII. *Cuneifolii.* Sand-blackberries

Rubus cuneifolius—Eureka blackberry.

Rubus audax—Oneco blackberry.

Rubus probabilis—perhaps includes varieties Nanticoke and Robinson.

X. *Alleghenienses.* Copsy Highbush blackberries

Rubus allegheniensis var. *neoscoticus.*

Variety: Taylor blackberry, also probably Agawam, Ancient Briton, Buckeye, Early Cluster, Early King, Eldorado, Erie, L'Amareux, Snyder, and Wilson Early.

XI. *Arguti.* Field Highbush blackberries

Rubus ostryifolius—varieties: Blowers, Brewer, Bundy, Early Harvest, Kenoyer, Kittatinny, Macatawa, Miller, Minnewaski, Ohmer, Perfection, Tory, Ward, and Watt.

Rubus louisianus—varieties: Crystal White blackberry and Iceberg.

Rubus frondosus—variety: Lawton blackberry.

Rubus lucidus—Rydb. variety:—Northy blackberry.

In the Pacific Northwest the Cut-leaf or Evergreen (Black Diamond) blackberry which originated from the European species, *Rubus laciniatus,* Wield, is cultivated. The Evergreen Thornless blackberry as well as Burbank Thornless are classified as forms of the European species *Rubus ulmifolius* var. *inermis.* The Himalaya berry which represents the European species *Rubus procerus,* P. J. Muell, is grown along the Pacific Coast.

In England several hybrids of the blackberry and raspberry have been produced. The progeny are relatively unproductive and of little economic importance, in spite of the fact that the fruits are of high dessert quality. As yet they have been used in this country for breeding only. They are Mahdiberry, Veitchberry, and Laxtonberry.

Improvement of the blackberry and dewberry. The Lawton blackberry was one of the earliest selections, followed by Snyder and Eldorado, and the Lucretia trailing dewberry. In the West one of the first selections from the wild trailing type was Aughinbaugh. This form is classified as *Rubus macropetalus,* the most complex polyploid of any of the cultivated forms (dodecaploid, (12x) 84 chromosomes). The loganberry, assumed to be a seedling of Aughinbaugh, was selected in 1881. Luther Burbank introduced the Phenomenal berry which is so similar to the loganberry that it is usually classed with it.

The youngberry resulting from a cross of Phenomenal x Mayes was introduced in 1926 and is at present replacing the loganberry in California. The boysenberry was introduced in 1935 from California and is similar to the youngberry. It is of unknown origin. The fruits are large and of excellent quality. The nessberry was introduced by the Texas Experiment Station and the Brainerd, a cross between the Himalaya berry and an erect-growing blackberry, was introduced by the United States Department of Agriculture.

Darrow [17] in 1937 stated that Eldorado (of Ohio origin) is still the principal erect blackberry, Lucretia the principal trailing blackberry or dewberry of the Eastern type, while the loganberry and youngberry are the leading trailing varieties of the western type. The Evergreen (Black Diamond) is the leading blackberry of the European type.

Thornless types. Cory Thornless was a result of a gene mutation and is a chimera. An outer layer of cells which have mutated to a thornless condition covers an inner core of nonmutated tissue.[15] Root cuttings of this chimera will, however, give only thorny plants. The Austin Thornless may have originated as a mutation from

Austin but it is not a chimera because root cuttings produce the thornless condition, which is also reproduced from seeds. Burbank Thornless is assumed to be a seedling of the European species *Rubus ulmifolius.* Cory Thornless and Burbank Thornless possess considerable sterility and are unproductive as are most thornless types. In Texas all thornless dewberries are reported to give low yields and the plants are susceptible to disease. The Evergreen Thornless is, however, as productive as the thorny types. *Rubus canadensis* which is native to North America is essentially thornless.

The Currant and Gooseberry

Currants and gooseberries which are closely related are grown extensively in Europe but only to a very limited extent in the United States.

Currant. The common red currant, *Ribes sativum* (Reichenb.) Syme, was cultivated for a number of years in the Netherlands, and around the Baltic Sea before it was brought to Massachusetts in 1620.

A considerable number of the 20 or more varieties grown in England in 1826, were introduced into this country and widely used until toward the end of the last century. Private breeders then crossed these imported sorts, resulting in the varieties Fay, Wilder, Red Cross, Diploma, and Perfection, which, according to Darrow [18] compose possibly 85 per cent of the present acreage.

The European black currant, *Ribes nigrum,* L., is extensively cultivated in Europe and to some extent in Canada, but has been banned in the United States largely because of extreme susceptibility to the white pine blister rust.

The American black currant, *Ribes americanum,* Mill. (Wild black currant), is much more resistant to this disease, but there is little demand for the fruit in this country and it is not grown commercially to any extent. The Buffalo Currant, *Ribes odoratum,* Wendl, which is grown to a very limited degree, produces fruit which, though large in size, has an unpleasant flavor. Both species are vigorous, hardy, and drought-resistant.

Several publications have been presented, classifying the various types of currants. Among these are the monographs of Janczewski,[29] Thayer,[40] Berger,[7] and Bailey.[5] Hedrick and his associates [27] also describe species and varieties in *The Small Fruits of New York.*

Gooseberry. The European gooseberry, *Ribes Grossularia,* L. Mill (*Grossularia reclinata*), came into cultivation before 1600 in England. During more than two centuries the number of varieties increased greatly until, by 1831, at least 722 were known. The greater size of the English gooseberries, as compared with the American, is probably responsible indirectly for the esteem in which it is held there. There were, for example, 171 gooseberry shows held in England in 1845, and interest and demand doubtless were responsible for the more extensive breeding program. The fact, however, that the European varieties were subject to mildew (*Sphaerotheca mors-uvae*) delayed breeding in this country until crosses of European and American varieties were obtained and spray materials to control mildew discovered. The American gooseberry, *Ribes hirtellum* (Michx), Spach (*Grossularia hirtella*) is the parent, either directly or by hybridization, of the American varieties. Since 1900 several varieties have been developed, namely, Oregon, Pearl, Red Jacket, Carrie, Poorman, and Como. All but Como were developed by private breeders. Of these, Poorman compares favorably in appearance and quality with the better European sorts.

Improvement of the currant and gooseberry. As indicated, the breeding of these fruits has never been particularly extensive in the United States. It is probable that their susceptibility to white pine blister rust and leaf diseases is the factor chiefly responsible for their lack of cultivation here. As a matter of fact, plantations of these berries are not encouraged, and indeed in some states are actively prohibited because they are instrumental in spreading the white pine blister rust. This disease does not spread from pine to pine, but from pine to currant and gooseberry, and back to pine. It injures all species of the white pine group which are among the most valuable timber trees of the northern United States. It is for this reason that Darrow [18] concluded that future improvement in the currant must lie along the line of resistance to disease.

There is a great need for fine-flavored attractive varieties of gooseberry which are disease-resistant. European varieties cross readily with American species, and this type of breeding might well prove very promising. The Glenndale has greater vigor than most other hybrids and far more than European sorts. Varieties possessing this vigor, and the quality of Poorman, together with the size of the European berries would be a welcome addition to American gardens.

The Blueberry

Since the cultivation and breeding of the blueberry is a comparatively recent undertaking, the description of findings is more or less brief. F. V. Coville of the United States Department of Agriculture was the first breeder of blueberries and the founder of the industry.[11]

The first wild berry selected for breeding was Brooks, which was found in a New Hampshire pasture in 1908. It was a highbush berry, *Vaccinium corymbosum*, L., selected with extreme care for its bush vigor, the sweet, slightly acid flavor of the fruits, and the dense bloom over the nearly black surface. In these respects it was superior to the lowbush blueberry *V. pennsylvanicum*, Ait. (*V. angustifolium*), or the Canada blueberry *V. canadense*, Kalm.

The first attempts to improve the berry were made in 1909 and 1910 and cross pollination was found to be an essential factor. It was also determined that ease of crossing among the different species of the United States is dependent on equality of chromosome number. Species of the most diverse characteristics will hybridize effectively provided they have the same number of chromosomes.

Russell, an earlier-ripening lowbush berry was the second selected for breeding. This berry together with Sooy, a wild berry from New Jersey, and Brooks were in general the parents of the first, second, and third generation hybrids from which, up to 1936, 68,000 pedigreed seedlings had been produced. Of these a number of the important, named varieties are: Pioneer (the first of the named varieties), Cabot (early), Katharine, Rancocas, Jersey, Concord, Stanley (large clusters, excellent flavor), and others. The seedling Dixi, named as recently as 1937, gives considerable promise for breeding, the largest berry having attained a size of 25.9 mm. (slightly over 1 inch).

Breeding of Fruits for Disease and Insect Resistance

The development of new varieties which are more resistant to the attacks of insects and disease than those now known is a paramount necessity, but as yet little progress has been made in this direction. In some fruits the need is more immediate than in others. Pear production, for example, will never be other than speculative until a blight resistant variety with the dessert and keeping qualities of Bartlett has been obtained. Breeding requires foresight, technical knowledge, energy, and patience; and with tree fruits, in which the number of generations is limited within the lifetime of any worker, these qualities are doubly essential. The attainment of high dessert quality has been in itself a difficult matter involving the growing of many thousands of seedlings. The addition of each newly desired characteristic multiplies the number of seedlings necessary, and the length of time required to produce an outstanding individual. Up to the present the tendency has been to retain those seedlings which were of high quality even though susceptible to disease, as long as the disease could be satisfactorily controlled. For example, a high proportion of McIntosh apple seedlings are quite susceptible to apple scab, but despite this fact the seedlings Cortland and Melba have been introduced and are gradually being planted commercially. Undoubtedly the cost of producing a bushel of fruit of these varieties would be lower if they were as resistant to scab as Baldwin, but obviously the primary demand of the public is for an apple of high dessert quality. Thus the introduction of an individual on the ground that it was highly resistant to the attacks of prevalent insects and diseases would be unjustifiable unless the fruits were also of desired quality.

Relation of Chromosome Constitution to Improvement of Fruits by Breeding

As has been previously indicated (Chapter 10) the chromosome constitution of a variety determines the viability of the gametes whose union results in the formation of new individuals. The extent to which the chromosome number differs, in the various species and varieties, is presented in Table 32. This table indicates the chromosome number of practically all species and varieties considered in this text.

The impossibility of including triploid varieties in a breeding program where a large number of individuals must be obtained is a serious handicap. For example the apple varieties Rhode Island Greening and Stayman Winesap are commercially desirable partly because of their vigorous trees and large fruits and thus would seem to offer promise as a parent. Due, however, to the chromosomal unbalance in the sperm nuclei and egg cells of triploids, the offspring obtained when such a variety is used as the male parent are very few, and, when used as the female parent, the progeny are weak and slow growing. Furthermore, the offspring are usually very unproductive, if not entirely sterile.

Furthermore, within a genus such as *Rubus*, in which the varieties contain different chromosome numbers, similar cases of an unbalanced chromosome constitution will occur in the offspring when certain crosses are made.[20, 44, 45] In *Rubus* the varieties within the blackberry group form a polyploid series from the diploid to the hexaploid condition.[17] Crosses cannot be made at random between the members of a polyploid series with the expectation of many, or fertile progeny. The chromosome number of the parents decidedly limits the nature of the offspring, even if the cross happens to be productive.[45] For example, the cross of diploid (2*x*) varieties of American blackberries with tetraploid varieties or species (4*x*) will for the most part give triploid (3*x*) progeny. The number of such offspring may be limited and partially or entirely sterile, with a consequent decrease in fruitfulness as compared with either parent. Experience has shown that very few progeny are obtained when a cross is attempted between two odd-numbered polyploids, as triploids (3*x*) and pentaploids (5*x*), or pentaploids (5*x*) and heptaploids (7*x*). Those obtained tend to be highly sterile and unproductive. Even crosses between even-numbered polyploids, such as 2*x* and 4*x*, will tend to give a large number of offspring which are inclined to be sterile. Crosses between polyploids having the same even number, such as 6*x* and 6*x*, tend to produce many progeny both fertile and fruitful.

Improvement of Fruits by Selection of Bud Mutations

Improvement of fruits by the selection of gene mutations occurring in the vegetative portions of a plant has recently become one of the outstanding developments in fruit production. According to Shamel and Pomeroy,[39] the earliest recorded bud mutation in fruits was reported by Peter Collinson in a letter to Linneaus, the famous botanist, in 1741. He described a russet apple produced on a green-fruited tree, and peaches and nectarines growing on the same tree. Charles Darwin listed the fruit bud sports which were known in England up to 1868.[21] Among these were the peach to nectarine and the reciprocal mutation, early- and late-ripening strains in the Grosse Mignonne Peach, russeted forms in apples, and changes in color of plum fruits.

Within the last two decades increasing search for bud mutations

TABLE 32. CHROMOSOME CONSTITUTION OF SPECIES

Type of Fruit	*Diploid (2x)*	*Triploid (3x)*	*Tetraploid (4x)*
Apple (17)[a]	*Malus sylvestris*—cultivated varieties *Malus baccata*	cultivated varieties	
Pear (17)	*Pyrus communis*—cultivated varieties *Pyrus serotina*	cultivated varieties	Possibly large fruited forms of Bartlett
Peach (8)	*Prunus Persica*—cultivated varieties		
Apricot (8)	*Prunus Armeniaca*—cultivated varieties		
Cherry (8)	*Prunus avium*—cultivated varieties		*Prunus Cerasus*—cultivated varieties Duke cherry
Plum (8)	*Prunus Salicina* *Prunus americana* *Prunus cerasifera* cultivated *Prunus hortulana* varieties *Prunus Munsoniana* *Prunus nigra* *Prunus Simonii* *Prunus Mahaleb*		*Prunus spinosa* (sloe)
Grape (19)	*Vitis labrusca* *Vitis vinifera* *Vitis vulpina* *Vitis aestivalis* *Vitis rupestris*		Tetraploid forms of Concord. "Gigas" strains of Vinifera: Muscat of Alexandria Sultanina Tokay
Strawberry (7)	*Fragaria vesca*		
Raspberry Blackberry Dewberry } (7)[b]	Raspberry *Rubus idaeus*— Lloyd George, Newman *Rubus idaeus* var. *strigosus*— Cuthbert, Ranere *Rubus occidentalis*— Cumberland Blackberry *Rubus allegheniensis* Ancient Briton *Rubus cuneifolius* Eureka *Rubus velox* Haupt, Jordan, McDonald *Rubus louisianus* Crystal White *Rubus ulmifolius* var. *inermis* Burbank Thornless	Raspberry European raspberry varieties: All Summer, Belle de Fontenay, November Abundance, White Queen Blackberry *Rubus mirus* Marvel (Florida Marvel) Blackberry-raspberry hybrids Kings Acre, Mahdi	Raspberry European raspberry varieties: Hailsham, LaFrance Blackberry American *Rubus allegheniensis* Eldorado, Snyder, Taylor *Rubus ostryifolius* Miller, Ward *Rubus frondosus* Lawton *Rubus probabilis* Nanticoke *Rubus velox* Texas Everbearing European *Rubus laciniatus* Evergreen or cut-leaved *Rubus procerus* Himalaya berry Raspberry-blackberry hybrid Veitchberry
Currant (8)	*Ribes sativum* *Ribes nigrum* *Ribes americanum*		
Gooseberry (8)	*Ribes Grossularia* *Ribes hirtellum*		
Blueberry (12)	*Vaccinium canadense*		Blueberry Highbush *V. corymbosum* Lowbush *V. pennsylvanicum* (*V. angustifolium*)

[a] The number after the kind of fruit gives the basic, haploid number of the genus.

[b] The chromosome numbers given for *Rubus* in this table have been taken from the material presented by Darrow in the Yearbook of the United States Department of Agriculture for 1937, pp. 532–533. The classification used is that of Bailey given in Gentes Herbarum II:271–423. 1932.

Hexaploid (6x)	*Heptaploid (7x)*	*Octoploid (8x)*	*Nonaploid or Above*
Prunus domestica *P. domestica* var. *insititia*			
Fragaria moschata		*Fragaria chiloensis* *Fragaria virginiana* cultivated varieties	
Blackberry American—*Rubus allegheniensis* *Rubus loganobaccus* Loganberry, Phenomenal berry *Rubus titanus* Mammoth, Cory var. *espinatus*: Cory Thornless Dewberry *Rubus flagellaris* Lucretia, Gardena European blackberry Bedford Giant	Blackberry European (hybrids) Laxtonberry	Dewberry American *Rubus flagellaris* var. *almus* Austin (Mayes) Ideal Wild Premo Windom	*Rubus macropetalus* (12*x*) Belle of Washington Cazadero Skagit Chief Washington Climbing

in fruits has resulted in the discovery of many. Successive, periodic reports of those which have been observed present an everincreasing number. Shamel and Pomeroy [89] enumerate a total of 863 recorded prior to May, 1936 in certain deciduous fruits. Nearly 50 per cent occurred in the apple, followed in order by the peach, cherry, and pear. At the same time Shamel and Pomeroy report the following number of mutations in other fruits (fruit and foliage characteristics only).

Apricot	8	Gooseberry	7
Blackberry and dewberry	30	Raspberry	3
Currant	13	Strawberry	2

Mutations involving change in the overcolor comprise by far the greater number observed, although it is probable that other characters mutate quite frequently. It is obvious from the nature of these mutations that not all are of economic value. In fact, both in citrus and deciduous tree fruits as well as in small fruits, mutations have occurred which are undesirable from the commercial point of view. For example, a seeded-berry mutation has been found in the Panariti Vinifera grape. Since the normal, seedless condition is desirable when the Panariti are dried to make "Zante currants," the seeded mutation is detrimental. Furthermore, corrugations observed in pear fruits in Western New York are also undesirable. (Fig. 85.) Apart from the mutation involving fruit shape there is no other observable difference. Removal of budding or grafting wood from this tree would produce many worthless trees. Thus it becomes extremely necessary that buds for propagation shall be carefully selected from plants which do not possess these undesirable variations.

The term "bud sport" is usually applied to the individual which has been propagated as a result of somatic variation involving presumably an entire bud. Mutations may, however, take place which do not involve the bud in its entirety. An individual plant growing from this bud would contain both mutated and nonmutated tissue and would be known as a "chimera." Some prefer to use the term "bud sport" to refer to those instances in which the entire bud contains only mutated tissue but this is not by necessity the meaning of the term. Since it is impossible to ascertain in most instances whether or not the mutation involves all or a portion of a bud, it is probable that the propagation of chimeras will continue, with the new individual considered as the result of a bud sport.

In addition to the mutations involving overcolor of fruit, those concerned with productivity or fruitfulness are of special interest. Several investigations were undertaken to determine whether certain observed differences in yield between trees or plants of a given clone were inheritable, or, in other words, had developed as a result of a mutation involving yield.[38, 42] These studies although they indicated that the particular differences in yield were the result of local environmental conditions did not prove that mutations involving yield might not occur. Sax later [38] concluded that hereditary differences in productivity may occasionally occur in an apple variety due to bud variation, but that bud mutations cause only a small amount of variability as compared to that caused by environment. In fact, Babcock and Clausen [2] cautioned that this type of experiment merely indicates that mutations of this sort are quite infrequent or that they are not a major cause of differences in fruitfulness. Mutations involving this factor have occurred in several fruits. In the sour cherry the lack of productivity was the re-

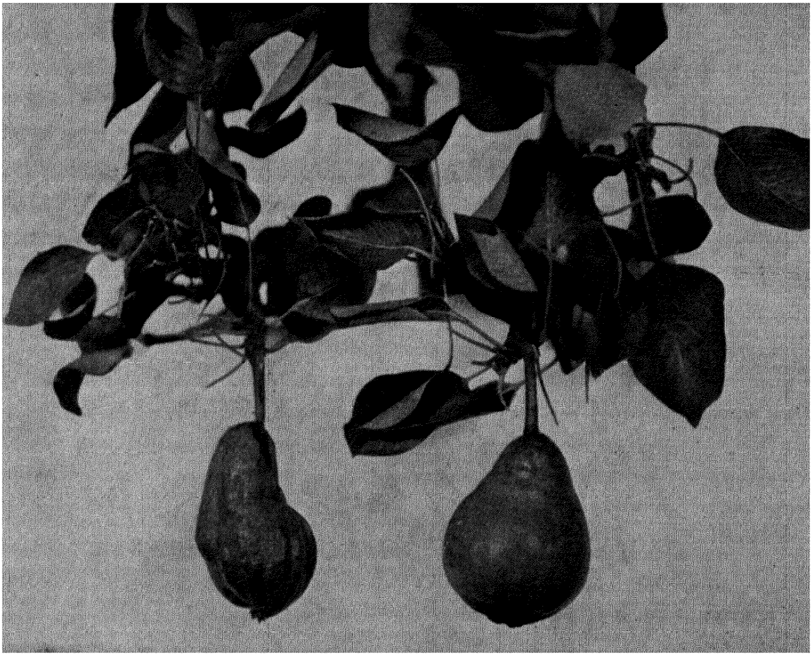


FIG. 85. Sectorial chimera (left) of Bartlett pear fruit on same tree with normal fruit (right).

sult of decreased resistance to frost injury as well as to a reduction in the formation of flower buds.[23]

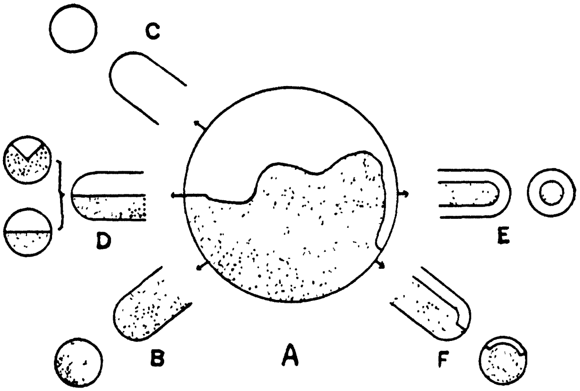
Importance of mutations in commercial fruit growing. A number of these mutations have become of great importance to the fruit-growing industry. Those of primary value are concerned with an alteration in the overcolor of the fruit, usually involving a change from the mottled, splashed, or striped pattern to a self-colored appearance. In addition [24, 25] the intensity and area of the color is usually increased. In a number of standard apple varieties, selection and propagation of fruit color mutations have produced more rapid improvement than could be obtained by breeding. Whether in these varieties other characteristics have mutated along with color has not yet been established. There are indications in a few instances that mutations involving other characters may have occurred, but they do not appear to be of much practical significance. Apple varieties differ greatly in the number of their mutations. The greatest number have been discovered in Delicious, of which Starking, Richared, and Shotwell Delicious are the better-known strains. Other commercially important varieties with some of their better known mutations are:

Gravenstein—Bank's, Red Gravenstein
Jonathan—Jonared, Blackjon
McIntosh—Blackmack
Northern Spy—Red Spy
Oldenburg—Red Duchess
Rome Beauty—Red Rome strains, Seeando Red Rome
Stayman Winesap—Staymared, Blaxtayman, Scarlet Staymared
Winesap—Seeando Winesap
York Imperial—Colora, Yorking

Many other varieties of minor importance have produced mutations, but they are of relatively little commercial significance as yet.

The naming of these mutations has complicated the problem of varietal nomenclature in the fruit industry. The public is unfamiliar with many of the new names, and thus it becomes impossible to take advantage of the sales appeal of the parent variety. In view of this fact there is a growing tendency on the part of the fruit growers to sell the fruits of the color mutation under the old varietal name or to prefix it with the word "red." In expositions fruits of the various color sports have frequently been substituted in place of the standard variety.

Recognition of chimeras in plants. The facility of recognition of chimeras in fruit plants depends in part upon the character of the mutation and its spatial arrangement in relation to nonmutated tissue. Three patterns called *sectorial*, *mericlinal*, and *periclinal* have been distinguished, but these do not necessarily include all chimeras.[30, 31] *Sectorial chimeras* refer to the arrangement in which the components occupy specific sectors penetrating to the center of the organ. Chimeras involving fruit size are rather readily recognized, since the fruits are either divided into unequal halves or else are ribbed, due to the fact that large and small sectors occupy adjacent positions. (Fig. 85.) If trees or herbaceous plants are sectorial chimeras each of the various organs of the plant may be of one of the three types, mutated cells, nonmutated, or both mutated and nonmutated cells.[31] As the plant develops, only those buds arising at the junction between mutated and nonmutated tissue will have a chimeral structure. The rest, forming the greater proportion, will be composed entirely of one or the other component. Chimeras of the sectorial pattern have been found to be relatively unstable. Buds selected at random from such a plant for propagation would include buds of all three types, and the plants developing from them would accordingly be pure for each of two components but would also include a considerable proportion of chimeras of the various types. (Fig. 86.)

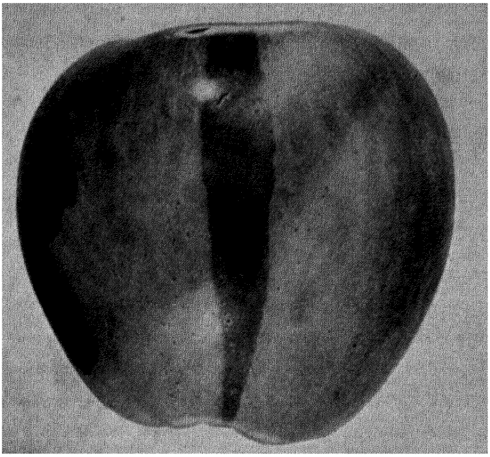


(Courtesey of Methuen and Co., London.)

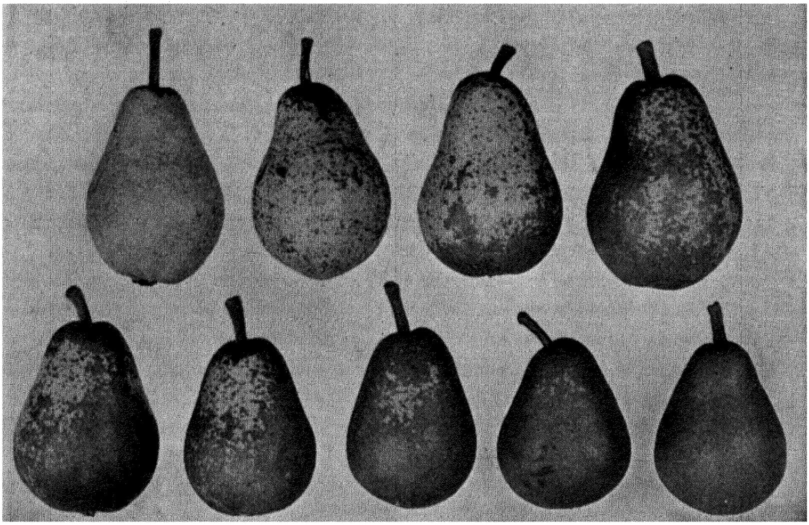
FIG. 86. Diagram illustrating how from the stem of a sectorial chimera (A) buds arise comprised wholly of nonmutated cells (B), of mutated cells only (C), and of both mutated and nonmutated cells (D, E, F). The growth from D will still be a sectorial chimera, while that originating at point E will be periclinal and at point F, mericlinal.

In *mericlinal chimeras* the mutated tissue comprises a layer (usually only a few cells thick) adjacent to nonmutated tissue. This type is probably more frequently found in nature than any other pattern. The mericlinal color chimeras may have the external appearance of sectorial chimeras but differ in that, instead of occupying a sector, the layer is only superficial. A variation in which a broad band of red color is present adjacent to the noncolored skin would be an example of a mericlinal chimera.[24] (Fig. 87.) These too are unstable. Those buds arising at the point of union between the mutated and nonmutated tissue would give rise to mericlinal chimeras. (Fig. 86.) Buds arising from within the center of the mutated tissue would give the periclinal chimera. Buds arising from without the strip of mutated tissue would give rise to the pure, nonmutated condition. The question has recently arisen as to whether several of the high color strains in the apple may not in reality be mericlinal chimeras.[13]

Periclinal chimeras refer to the spatial arrangement in which the mutated tissue surrounds the nonmutated, or *vice versa* in a hand-in-glove fashion. The outer layer of mutated tissue may be one to three cell layers thick. Unless it includes at least the second layer it is believed it cannot be propagated sexually since the cells which give rise to sporogenous tissue in higher plants are at least subepidermal in position. This indicates that if a new variety involving a change in overcolor is a periclinal chimera with the layer one cell thick, the sex cells produced will be of the constitution of the inner or core tissue. For example, in the original tomato and nightshade graft-hybrid chimeras obtained by grafting,[43] the individuals produced exhibited an epidermis of tomato and a core of nightshade or *vice versa.* In each case the individuals obtained by sexual propagation from these periclinal chimeras were either tomato or nightshade, depending upon which type occupied the core. A thornless sport of the Evergreen blackberry (*Rubus laciniatus*) has been obtained which is a chimera having a thin layer of thornless tissue overlying a nonmutated, thorny type.[16] A thornless sport of the youngberry has also been discovered. When propagated by root cuttings or when freezing kills the tops, the shoots from below the crown are thorny. Thus these thornless types are periclinal chimeras, and the production of shoots from the roots represents the best index for recognizing a periclinal chimera, since the shoots produced from roots originate from within the inner core or stele. Chimeras involving overcolor in which the entire surface of the fruit is affected are of the periclinal type. The periclinal chimera is the most stable of all patterns and may be propagated vegetatively for an indefinite period. Only infrequently does the inner core of tissue force its way out and include the epidermis



Mericlinal chimera on Stayman Winesap apple fruit



(Courtesy Roy Gibson, The Greening Nursery Company, Monroe, Michigan.)

Mottled Bartlett pear russet chimeras

FIG. 87. Types of chimeras in the apple and pear.

also. In such a case one might hastily assume that a mutation had occurred only recently, when as a matter of fact it actually occurred long before. As far as is known at present, mutations may occur at any time in the life of an individual and in any tissue or organ, and we become conscious of them only after the original mutating cell has given rise to millions of progeny.

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17

COST OF MANAGEMENT OF THE ORCHARD, VINEYARD, AND SMALL FRUIT PLANTATION

As with any other commodity, the price received for fruit must be greater than its cost of production and marketing or the grower cannot continue in business. Practically, whenever the price received is less than the expense involved together with a reasonable profit, there is an overproduction of that commodity. While it is true that there are seasons when the price received for certain fruits does not bear any close relation to the cost of production this cannot continue for an extended period. If it does continue, acreage must be reduced, new outlets found, cost of production reduced, or finally some sort of regulation may be requested in order to save the industry. The latter should be a last, not a first, resort.

These situations arise at times because fruit competes in the market with many other products which may be grown in a region where labor and other overhead charges are much lower. The producers of most kinds of agricultural commodities undergo this experience in some years. To stabilize the industry and to reduce its hazards is the ultimate purpose of all those who are seriously concerned with the fruit industry.

It is axiomatic that the cost of production of a unit of any fruit commodity is determined in large part by the yield per plant or per acre. As yields go up costs per bushel usually go down, and, if quality does not suffer, then the earnings on the investment increase. Farm surveys have shown that mere increase in quantity has not compensated for low quality, and that efficiency of operation and management is of vital importance. Unfortunately the production of high quality fruit has not always meant the greatest net returns. There are certain markets and economic areas where fruit of somewhat lower quality, produced at a minimum cost, has been the most profitable. Such a situation is unhealthy and in the best fruit-growing regions the opposite condition prevails. Overproduction of a mediocre product has been the curse of the fruit industry, and methods and means are constantly sought for the disposal of cull fruit without allowing it to compete in the fresh fruit market.

The first objective should, therefore, be to know the cost of growing an orchard, the cost of producing a bushel or unit of fruit, and wherein wise economies can be practiced. It is our purpose here to assemble in convenient form some representative data with the understanding that such costs vary from place to place.*

The Apple

Cost of establishing the orchard. The cost of establishing and bringing an apple orchard into bearing varies with the section of the country concerned, as well as with the current price of land, labor, and materials.

Accurate data covering establishment and production costs for a Stayman Winesap-Delicious orchard in Ohio are given in Tables 33 and 34. In this study the trees produced their first crop of fruit in 1921 when the orchard was in its 7th year. Until 1923 (the 9th year) no crop was sufficiently heavy to cover the operating expense. The value of the combined crops produced in the 7th and 8th years (1921 and 1922) was just sufficient to balance the expenses of the eighth year (1922). In this orchard the grower would have found it necessary to finance the enterprise for seven years before it became self-supporting. The total cumulative cost for the period was $6.23 per tree or $218.05 per acre of 35 trees. It must be understood that these figures include interest on the investment and equipment, as well as payment for the owner's labor and supervision. For this reason they are not representative of the actual cash outlay which would be considerably less.

In this particular case the cost of bringing the tilled orchard into bearing is somewhat greater than for the mulched block of trees. This difference was counterbalanced, however, by a slightly greater production in the tilled block during its early years. As the orchard approached full bearing in its 16th to 20th years, the portion under mulch increased slightly in production.[2] This was possibly due to better soil moisture conditions under this system of culture. During this latter period (1930 to 1934) the trees grown in sod plus mulch averaged 477.4 bushels per acre, produced at a cost of 42 cents per bushel. The trees in tillage plus cover crops averaged 458.5 bushels per acre produced at a cost of 40 cents per bushel. Both systems were entirely satisfactory in tree growth and yield and produced better-than-average crops at all times.

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* The following tables are not entirely comparable owing to the fact that certain items are included in some of the original surveys and not in others. This is particularly true of packages, packing costs, and owner supervision. The headings and contents of each table should be examined before generalizations are drawn.

TABLE 33. ESTABLISHING AND PRODUCTION COSTS OF A STAYMAN WINESAP-DELICIOUS APPLE ORCHARD IN OHIO, 1915–1929, IN CULTIVATION, PLUS COVER CROPS.*

(Calculations on the basis of one acre containing 35 trees set 35 x 35 feet)

Items	*1915*	*Yearly Average 1916 to 1920*	*Yearly Average 1921 to 1925*	*Yearly Average 1926 to 1929*
Man labor per hour	$ 0.20	$ 0.302	$ 0.356	$ 0.375
Horse labor per hour	.20	.312	.356	.350
Tree	3.500	—	—	—
Planting tree	1.155	—	—	—
Cultivation—man and team	7.805	8.330	9.611	14.018
Miscellaneous hand labor	0.875	1.316	0.441	6.239
Pruning and brush disposal	—	0.392	2.289	11.646
Tree guards [a]	—	0.700	—	—
Cover crop seed	5.740	2.618	4.718	3.850
Fertilizer and application	—	—	0.819	1.960
Number of spray applications	—	1.2	5.6	6.0
Spraying: labor, machine, and materials	—	2.135	18.344	47.976
Thinning	—	—	—	7.131
Picking	—	—	6.342	19.163
Hauling to storage	—	—	1.953	6.221
Grading	—	—	4.179	13.387
Rental of small tools and crates	0.350	0.350	3.045	6.930
Supervision	5.915	6.440	11.802	14.770
Interest and taxes	10.080	16.933	30.093	11.471
Total cost per acre	$35.420	39.214	93.646	164.762
Yield per acre (bushels)	—	—	92.794	286.760
Value of fruit per acre	—	—	153.132	492.669
Cost per tree	1.012	1.120	2.676	4.707
Cost per bushel (48 lb.)	—	—	1.009	0.474

[a] Used only in 1916.

Production costs. There have been few accurate and complete cost account studies reported for orchards. An attempt has been made to secure and tabulate such data as will give a typical picture of Eastern and Western orchard conditions. These data are presented in Tables 35 and 36 and furnish information which will

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* Compiled from: Ellenwood, C. W., 1930. The cost of developing an apple orchard. Ohio Agr. Exp. Sta. Bull. 456.

TABLE 34. ESTABLISHING AND PRODUCTION COSTS OF A STAYMAN WINESAP AND DELICIOUS APPLE ORCHARD IN OHIO, 1915–1929, IN GRASS MULCH [*]

(All calculations on the basis of one acre set 35 x 35 feet
and containing 35 trees per acre)

Items	*1915*	*Yearly Average 1916 to 1920*	*Yearly Average 1921 to 1925*	*Yearly Average 1925 to 1929*
Man labor per hour	$0.20	$ 0.302	$ 0.356	$ 0.375
Horse labor per hour	.20	.312	.356	.350
Tree	3.500	—	—	—
Planting tree	1.750	—	—	—
Mowing: man and team	.875	1.813	2.233	2.502
Misc.: Hand labor	.735	1.176	.819	1.111
Pruning and brush disposal	—	.420	2.345	11.512
Tree guards [a]	—	.700	—	—
Mulch and application	1.715	.728	8.099	9.677
No. of spray applications	—	1.2	5.6	6.0
Spraying: labor, machine, and materials	—	2.128	18.354	47.976
Fertilizer and application	—	—	.819	1.960
Interest and taxes	10.115	15.456	24.927	12.250
Thinning	—	—	—	7.079
Picking	—	—	6.426	15.330
Hauling to storage	—	—	1.687	4.935
Rental of crates and small tools	.350	.350	3.010	5.915
Grading	—	—	3.654	10.622
Supervision	5.915	6.440	11.802	14.770
Total cost per acre	24.955	29.211	84.175	145.639
Yield per acre (bushels)	—	—	81.46	227.281
Value of fruit per acre	—	—	130.704	392.989
Cost per tree	.713	.835	2.405	4.161
Cost per bushel (48 lb.)	—	—	1.033	.641

[a] Used only in 1916.

be used in comparing some of the factors discussed in the following pages.

Apple orchard management. It should not be assumed that a few factors may be selected which can be so modified as to insure the success of the orchardist. The most successful growers give proper attention to all factors beginning with the selection of the orchard site and continuing through all the managerial practices of tree training, crop production, harvesting, and marketing.

Certain factors, however, exert greater influence on results or are more easily controlled than others. The orchardist should realize that real economy of production does not necessarily consist in the

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[*] Compiled from Ellenwood, C. W., 1930, The cost of developing an apple orchard. Ohio Agr. Exp. Sta. Bull. 456.

TABLE 35. COST OF PRODUCING APPLES IN YAKIMA VALLEY, WASHINGTON

	*1916** 120 orchards Average acreage 6.4 Average value per acre $950.14 Average yield per acre 432 boxes			*1926 to 1928†* 43.7 orchards Average acreage 14.1 Average value per acre $976.57 Average yield per acre 484.5 boxes		
Items	*Cost per Acre*	*Cost per Box*	*Per Cent of Total Cost*	*Cost per Acre*	*Cost per Box*	*Per Cent of Total Cost*
Maintenance labor						
Pruning	$ 13.14	$0.030	3.71	$ 15.20	$0.031	2.99
Brush removal	4.57	.011	1.29	4.22	.009	.83
Fertilizing	3.80	.009	1.07	1.38	.003	.27
Cultural operations	11.77	.027	3.33	5.14	.011	1.01
Spraying	12.94	.030	3.66	13.33	.027	2.62
Irrigating	4.38	.010	1.24	12.04	.025	2.37
Thinning	12.35	.029	3.49	21.78	.045	4.29
Propping	1.57	.004	.44	1.96	.004	.39
Miscellaneous	2.68	.006	.76	1.88	.004	.37
Total maintenance labor	67.20	.156	18.99	76.93	.159	15.14
Handling labor						
Hauling shooks	1.66	.004	.47	1.94	.004	.39
Hauling (orchard)	8.84	.020	2.50	10.17	.021	2.00
Picking	26.38	.061	7.45	39.24	.081	7.72
Grading and packing	45.55	.105	13.87	192.33[a]	.397	37.86
Hauling packed fruit	7.12	.017	2.01	10.17	.021	2.00
Hauling culls	.49	.001	.14			
Supervision				2.40	.005	.47
Miscellaneous				.48	.001	.10
Total handling labor	90.04	.208	25.44	256.75	.530	50.53
Materials						
Fertilizer	7.01	.016	1.98	5.28	.011	1.04
Spray materials	12.21	.028	3.45	18.16	.037	3.58
Gas, oil, electricity	.83	.002	.24	11.92	.025	2.35
Boxes, paper, etc.	62.77	.145	17.74			
Miscellaneous	.12	.001	.03	.99	.002	.19
Total materials	82.94	.192	23.44	36.35	.075	7.16
Overhead (fixed) costs						
Interest	86.37	.200	24.40	58.59	.121	11.53
Buildings	4.32	.010	1.22	12.80	.026	2.52
Equipment	9.21	.021	2.61	27.96	.058	5.50
Irrigation system				4.50	.009	.89
Land tax	10.98	.025	3.10	10.40	.022	2.05
Water tax	2.06	.005	.58	9.23	.019	1.82
Insurance	.79	.002	.22	2.50	.005	.49
Interest on costs				12.04	.025	2.37
Total overhead	113.73	.263	32.13	138.02	.285	27.15
Grand total	353.91	.819	100.00	508.05	1.049	100.00

[a] Includes packing materials.

* Compiled from: Miller, G. H., and Thomson, S. M., 1918, Cost of producing apples in Yakima Valley, Washington, U. S. D. A. Bull. 614.

† Compiled from: Johnson, N. W., 1930, Economic aspects of apple production in Washington. Wash. Agr. Exp. Sta. Bull. 239.

TABLE 36. COST OF PRODUCING APPLES IN WESTERN NEW YORK

	1910 to 1915 * 218 orchards[a] Average acreage 14 acres Average yield per acre 245.3 bu. Investment per acre $500.00			*1926 to 1928* † 123 orchards Average yield per acre 117 bu.		
Items	*Cost per Acre*	*Cost per Bushel*	*Per Cent of Total Cost*	*Cost per Acre*	*Cost per Bushel*	*Per Cent of Total Cost*
Maintenance labor						
Pruning	$ 4.85	$0.020	3.62	$ 8.40	$0.072	7.82
Brush removal	2.14	.009	1.60			
Fertilizing	2.21	.009	1.65	1.82	.016	1.70
Cultural operations	7.11	.029	5.31	5.11	.044	4.76
Spraying	6.80	.028	5.08	8.76	.075	8.16
Thinning	.89	.003	.66			
Miscellaneous	.75	.003	.56			
Total maintenance labor	24.75	.101	18.48	24.09	.207	22.44
Handling labor						
Hauling (orchard)	6.19	.025	4.62	7.52	.064	7.00
Picking	13.99	.057	10.44	12.88	.110	12.00
Grading and packing	6.34	.026	4.73	9.66	.083	9.00
Handling culls				4.29	.037	4.00
Total handling labor	26.52	.108	19.79	34.35	.294	32.00
Materials						
Fertilizer	10.06	.041	7.51	3.65	.031	3.40
Spray materials	8.65	.035	6.46	12.41	.106	11.56
Boxes, paper, etc.	28.68	.117	21.41			
Miscellaneous	1.68	.007	1.25	1.46	.012	1.36
Total materials	49.07	.200	36.63	17.52	.149	16.32
Overhead (fixed) costs						
Interest	25.72	.105	19.20	18.25	.156	17.00
Buildings	1.99	.008	1.49			
Equipment	3.17	.013	2.37	9.49	.081	8.84
Land tax	2.30	.009	1.72	3.65	.031	3.40
Insurance	.43	.002	.32			
Total overhead	33.61	.137	25.10	31.39	.268	29.24
Grand total	133.95	.546	100.00	107.35	.918	100.00

[a] Trees averaged 40 years old.

* Compiled from: Miller, G. H., 1920, Cost of producing apples in five counties in Western New York, 1910–1915, U. S. D. A. Bull. 851.

† Compiled from: LaMont, T. E., and Williamson, P. S., 1936, Farm management for fruit growers. Cornell Univ. Ext. Bull. 355.

elimination of any regular orchard practice. Certain operations may be modified so as to effect savings, but not eliminated. True economy is more easily secured by attention to those details which increase yields. A reduction of overhead and a more efficient use of labor are also desirable objectives. In some cases, diversification of crops may prove to be the turning point in making the enterprise profitable.

Yield. For economy of production, high yields are of great importance and should be given primary consideration. From a purely economic point of view an Eastern grower should not be satisfied with an average production of less than 200 bushels of apples per acre. As the yield increases above this figure the cost of production decreases and profits increase, except in rare cases of overintensive operations or practices. In the Northwest, yields of 500 to 600 bushels per acre are common and necessary if the orchardist is to realize a satisfactory return from his investment and labor.

As can be seen in Table 36, yield has a major influence on the cost per bushel. The value of high yields is also evident in Yakima Valley, Washington. (Table 35.) With production costs per acre averaging over three times as much as in New York, the cost remains at slightly over $1.00 per box in 1926–28 due to the larger yields secured.

It will be noted that in most cases the cost per bushel is reduced as the yields increase. Data from Berrien County, Michigan, in 1935 [8] are given in Table 37 and bear out this fact.

TABLE 37. APPLE YIELDS AND PRODUCTION COSTS IN BERRIEN COUNTY, MICHIGAN, 1935 [8]

Yield per Acre	*Production Costs per Acre*	*Production Costs per Bushel*
64 bushels	$ 61.59	$0.964
121 "	97.39	.804
222 "	115.03	.519
312 "	157.85	.506
436 "	167.42	.383

Overhead. Overhead costs vary widely and may easily become a major factor in the cost of production. Efficient management becomes of prime importance. High-priced land should be avoided because in most regions, suitable sites are available at reasonable prices. This of course does not imply that unfavorable soils should be used merely because the land is cheap. A good site should be selected but not in a location where high prices prevail due to proximity to residential or manufacturing districts. Land is usually charged against the crop at the rate of 5 to 6 per cent interest plus taxes.

Equipment is necessary for proper operation of any farm, but this should be carefully selected and in keeping with the size of the unit. A satisfactory equipment charge is about 5 to 6 per cent interest, 15 to 18 per cent depreciation, plus necessary repairs. These charges are necessary if the cost of replacement and operation is to be properly prorated for the life of the machinery.

Some farmers prefer to charge tractor operation on an hourly basis. In New York in 1930 the cost for tractors including fuel, depreciation, interest, repairs, and all other items was found to be $.76 for each hour of use. The charges in other states vary from $.75 to $1.50 per hour, but $.75 to $1.00 seems to be a reasonable figure.

Truck and auto use may be charged at a set rate per mile (usually about $.04) or at a given rate per hour, which is about the same as for tractors.

Buildings should not be elaborate but must be adequate to facilitate the proper handling of fruit, and storage of equipment. Building charges should include interest at 5 to 6 per cent, insurance, taxes, and repairs.

Crop insurance against hail is an overhead charge which may be economical in regions which frequently suffer from this type of damage.

Interest on operating costs is frequently omitted from cost accounts but is an item which should be given consideration if the enterprise is to be run on a businesslike basis.

Size of orchards. Within reasonable bounds the larger the acreage in apples the lower the production cost will be per acre and per bushel. This depends, of course, on local conditions, soil, and the facilities and ability of the individual grower. Where tractors are used the acreage should probably be larger.

In Western New York an apple orchard of 15 to 20 acres seems sufficiently large in case it is part of a somewhat diversified farm. In the irrigated regions of the Northwest where climatic conditions favor rapid growth and where thinning and other intensive practices are followed, the most economical size is also about 20 acres. Virginia apple growers are more inclined to specialize, and blocks of 100 to 500 acres or even larger are common and appear to be good economic units for that section. There is a tendency to develop one-family units of 40 to 75 acres in many regions, and these have proven to be economical of management.

Marketing costs. The cost of placing fruit in the hands of the consumer varies widely in different regions. This is a local problem which does not lend itself to general analysis, and economical measures must be determined by the individual grower. Those orchardists who sell large quantities of fruit at a roadside stand often have very low marketing costs unless their buildings are elaborate. Local retail and wholesale distribution may also be carried on at small expense.

Rail or boat shipment adds considerably to the expense of marketing. The cost of shipping a bushel of apples from Western New York to New York City averages about $.25. Shipments from the Northwest to the same market have a railroad and refrigeration charge of about $.75 per bushel.

The Pear

Production costs and management factors. Representative pear production costs for Washington (1927–28) are given in Table 38, and for New York (1930) in Table 39. The costs in Washington are principally for cannery production. Pears for packing were produced in Washington in 1932[3] at a cost of $310.80 per acre (355.4 boxes) or $.87 per box. Under similar conditions cannery pears were produced at $183.48 per acre (with a yield of 9.77 tons) or $18.77 per ton. The difference in per acre cost is largely due to the harvesting and packing operations.

A Washington survey[3] of conditions in 1932 gives a good illustration of the influence of yield on the cost of production. In this study the six highest yielding orchards produced 26.0 tons of fruit per acre at a cost of $11.61 per ton while the six poorest produced 2.9 tons per acre at a cost of $63.55 per ton. The total costs were $112.44 and $110.17 per acre respectively.

The Peach

Production costs and management considerations. The cost of producing peaches in Washington in 1927–28 and in New Jersey in 1931 is presented in Tables 40 and 41. Under the conditions existing in the East at the time when this study was made, the cost and returns from peach production were more dependent upon

TABLE 38. COST OF PRODUCING PEARS IN WASHINGTON 1927–28 *

(Sold largely to cannery)

WENATCHEE VALLEY	YAKIMA VALLEY
Number of farms 4	Number of farms 22
Age of trees 16 yrs.	Age of trees 17.7 yrs.
Land invest. per a. $1417.54	Land invest. per a. $1219.58
Equip. " " " 28.72	Equip. " " " 23.31
Irr. Sys. " " " 94.19	Irr. sys. " " " 14.30
Av. yield per a. 11.01 T	Av. yield per a. 11.84 T

Items	*Cost per Acre*	*Cost per Ton*	*Per Cent of Total Cost*	*Cost per Acre*	*Cost per Ton*	*Per Cent of Total Cost*
Maintenance labor costs						
Pruning	$ 17.09	$ 1.55	4.86	$ 21.00	$ 1.77	7.23
Brush disposal	5.12	.47	1.45	4.32	.36	1.49
Cultural operations	9.91	.90	2.82	10.89	.92	3.75
Spraying	26.74	2.43	7.61	22.82	1.93	7.86
Irrigating	17.29	1.57	4.92	11.29	.95	3.89
Thinning	13.73	1.25	3.91	3.85	.33	1.33
Propping	6.26	.57	1.78	.69	.06	.24
Cutting blight				4.26	.36	1.47
Miscellaneous	3.02	.27	.86	4.34	.37	1.50
Total maintenance labor	99.16	9.01	28.21	83.46	7.05	28.76
Materials						
Fertilizer	10.44	.95	2.97	8.96	.75	3.09
Spray materials	14.88	1.35	4.23	15.26	1.29	5.26
Miscellaneous	1.32	.12	.38	2.45	.21	.84
Total materials cost	26.64	2.42	7.58	26.67	2.25	9.19
Harvesting cost						
Picking	46.44	4.22	13.21	52.52	4.43	18.10
Hauling (orchard)	11.01	1.00	3.13	9.60	.81	3.31
Hauling to warehouse	14.75	1.34	4.20	11.26	.95	3.88
Supervision	4.18	.38	1.19	5.33	.45	1.83
Total harvesting cost	76.38	6.94	21.73	78.71	6.64	27.12
Overhead costs						
Interest on land	85.05	7.73	24.20	73.17	6.18	25.21
Equipment	7.29	.66	2.07	6.62	.56	2.28
Irrigation sys.	15.98	1.45	4.55	2.51	.21	.87
Land tax	20.49	1.86	5.83	8.49	.72	2.93
Water tax	13.39	1.22	3.81	3.43	.29	1.18
Insurance				1.07	.09	.37
Interest on costs	7.10	.64	2.02	6.06	.51	2.09
Total overhead costs	149.30	13.56	42.48	101.35	8.56	34.93
Grand total	351.48	31.93	100.00	290.19	24.19	100.00

* Compiled from: Johnson, N. W., 1930, Economic aspects of the Washington fruit industry. Apricots, cherries, peaches and pears. Wash. Agr. Exp. Sta. Bull. 236.

Note: A bushel of pears weighs 50 pounds. A western box of pears weighs 46 pounds.

TABLE 39. COST OF PRODUCING PEARS IN NEW YORK 1930 *

Average of four accounts
Average 3.6 acres pears each farm
Average yield 99 bushels per acre

Items	*Cost per Acre*	*Cost per Bushel*	*Per Cent of Total Cost*
Growing costs			
Manure	$ 5.63	$0.057	9.22
Fertilizer: 7 lbs. per acre	.21	.002	.35
Spray or dust	3.68	.037	6.03
Man labor 10.2 hrs.	3.68	.037	6.03
Horse labor 6.8 hrs.	1.32	.013	2.16
Tractor and tools 0.6 hr.	.49	.005	.80
Other equipment	1.94	.020	3.18
Other growing costs	.69	.007	1.13
Total growing costs	17.64	.178	28.90
Harvesting and handling cost			
Man labor (harvest) 52.9 hrs.	19.73	.199	32.32
Horse " " 5.3 "	.97	.010	1.59
Truck "	.83	.008	1.36
Other equipment (harvest)	.83	.008	1.36
Packing and containers	13.68	.138	22.41
Use of buildings	.07	.001	.12
Miscellaneous	.14	.002	.23
Total harvesting and handling cost	36.25	.366	59.39
Use of land	7.15	.072	11.71
Grand total	61.04	.616	100.00

yield than any other factor, as is the case in most tree fruit crops.

A study in California in 1933 [5] also indicates the value of high yields in keeping costs at a minimum and profits at a high level. The most profitable orchards in this survey produced 13.6 tons (566.66 bu.) at a net profit of $98.86 per acre. The less profitable orchards produced 8.6 tons (358.33 bu.) at a net profit of $5.99 per acre.

The Cherry

Development costs. Data on the cost of establishing and developing a cherry orchard are available from Michigan and are presented in Tables 42 and 43.

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* Compiled from: Harriott, J. F., and Vaughan, L. M., 1933, Cost accounts on New York Farms. Cornell Univ. Agr. Exp. Sta. Bull. 554.

TABLE 40. COST OF PRODUCING PEACHES IN WASHINGTON 1927–1928 *

WENATCHEE VALLEY	YAKIMA VALLEY
Number of farms 25	Number of farms 26
Age of trees 15.4 yrs.	Age of trees 17 years
Land invest per a. $914.63	Land invest per a. $1151.95
Equip. " " " 23.46	Equip. " " " 35.38
Bldg. " " " 2.62	Bldg. " " " 40.65
Irr. sys. " " " 53.90	Irr. sys. " " " 22.24
Av. yield per a. 768 boxes [a]	Av. yield per a. 1035 boxes [a]

Items	*Cost per Acre*	*Cost per Box*	*Per Cent of Total Cost*	*Cost per Acre*	*Cost per Box*	*Per Cent of Total Cost*
Maintenance labor cost						
Pruning	$ 24.82	$0.032	6.71	$ 18.17	$0.018	3.80
Brush disposal	4.14	.006	1.12	5.84	.006	1.22
Cultural operations	7.74	.010	2.09	12.63	.012	2.64
Spraying	3.94	.005	1.07	7.69	.007	1.61
Irrigating	10.97	.014	2.97	20.93	.020	4.38
Thinning	16.27	.021	4.40	9.84	.010	2.06
Propping	2.50	.003	.68	3.11	.003	.65
Miscellaneous	.51	.001	.14	7.21	.007	1.51
Total maintenance labor	70.89	.092	19.18	85.42	.083	17.87
Materials						
Fertilizer	7.52	.010	2.04	14.59	.014	3.05
Spray materials	6.20	.008	1.68	13.84	.013	2.90
Boxes, paper, nails	79.45	.103	21.49	99.18	.096	20.75
Miscellaneous				4.90	.005	1.03
Total materials cost	93.17	.121	25.21	132.51	.128	27.73
Harvest labor costs						
Picking	36.27	.047	9.81	54.46	.053	11.39
Hauling (orchard)	10.29	.013	2.78	11.59	.011	2.42
Hauling to warehouse	14.59	.019	3.95	14.90	.014	3.12
Packing	24.36	.032	6.59	36.85	.036	7.71
Lidding and "flunky"	7.83	.010	2.12	12.32	.012	2.58
Supervision	7.37	.010	1.99	11.80	.011	2.47
Total harvesting cost	100.71	.131	27.24	141.92	.137	29.69
Overhead costs						
Interest on land	54.88	.071	14.85	69.12	.067	14.46
Equipment	6.10	.008	1.65	8.77	.008	1.83
Buildings	.29	.001	.08	5.03	.005	1.05
Irrigation system	7.54	.010	2.04	4.14	.004	.86
Land tax	13.32	.017	3.60	9.02	.009	1.90
Water tax	13.76	.018	3.72	9.21	.009	1.93
Insurance	.21	.000	.06	1.38	.001	.29
Interest on costs	8.76	.011	2.37	11.42	.011	2.39
Total overhead costs	104.86	.137	28.37	118.09	.114	24.71
Grand total	369.63	.481	100.00	477.94	.462	100.00

[a] A western peach box holds approximately ½ bushel.

* Compiled from: Johnson, N. W., 1930, Economic aspects of the Washington fruit industry. Apricots, cherries, peaches, pears. Wash. Agr. Exp. Sta. Bull. 238.

TABLE 41. COST OF PRODUCING PEACHES IN NEW JERSEY 1931 *

Average of 20 farms with a total of 338.5 bearing acres
Average yield 215 bu. per acre

Items	*Cost per Acre*	*Cost per Bushel*	*Per Cent of Total Cost*
Cost up to harvest			
Fertilizer 319 lbs. per acre	$ 5.31	$0.025	4.65
Cover crop	.64	.003	.56
Spray material	9.68	.045	8.48
Man labor 46 hrs. per acre	12.21	.057	10.70
Horse labor 7 hrs. per acre	1.33	.006	1.17
Machine use 4 hrs. per acre	.27	.001	.24
Tractor use 6 hrs. per acre	4.25	.020	2.72
Miscellaneous	8.26	.038	7.24
Total cost until harvest	41.95	.195	36.76
Harvesting cost			
Man labor 79 hrs. per acre	20.52	.095	17.98
Horse labor 7 hrs. per acre	1.23	.006	1.08
Machine use 7 hrs. per acre	.49	.002	.43
Tractor use 15 hrs. per acre	.14	.001	.12
Truck use	.53	.003	.46
Containers	25.18	.117	22.07
Miscellaneous	.73	.003	.64
Total harvesting cost	48.82	.227	42.78
Overhead			
Interest on orchard investment @ 5%	8.91	.041	7.81
Depreciation of machinery and equipment	2.57	.012	2.25
Taxes	5.06	.023	4.43
Interest on costs @ 2%	1.20	.006	1.05
Total overhead costs	17.74	.082	15.54
Total production and harvesting costs	108.51	.504	95.08
Marketing costs			
Man labor 5 hrs. per acre	1.22	.006	1.07
Truck use 34 mi. per acre	3.08	.014	2.70
Ferry	.41	.002	.36
Cold storage	.90	.004	.79
Total marketing costs	5.61	.026	4.92
Total prod., harv., and mark. costs	114.12	.530	100.00

* Compiled from: Waller, A. G., and Carncross, J. W., 1933, Facts on fruit and vegetable farming in New Jersey, 1926–1931. N. J. Agr. Exp. Sta. Bull. 555.

Production costs. Information which is more-or-less representative of Eastern and Western cherry production costs will be found in Tables 44 and 45. Production fluctuates appreciably in the East due mainly to climatic factors. Average yields, however, may be assumed from the data which are available and prices per pound calculated to give a comparison of the East and the West.

Table 44 gives average production costs of $158.46 per acre for Michigan, which are quite typical of well-managed Eastern orchards. Using this cost as a base, a 6,000-pound crop (easily secured under average conditions) would cost 2.64 cents per pound to produce. Sweet cherries will yield 8,000 pounds under good conditions, and this would reduce the price to 1.76 cents per pound. The cost of harvesting and packing sweet cherries is approximately 4 to 4½ cents per pound. Montmorency cherries should produce 12,000 to 15,000 pounds per acre under good conditions, which would result in a price of 1.32 and 1.06 cents per pound respectively. The cost of harvesting sour cherries for commercial canning is approximately 1 cent per pound. This example illustrates the importance of high yields in securing economical production. In many cases such yields are not secured or else management costs are high, and growers in the East have faced a serious situation with the prevailing prices paid by canneries. In Table 45 the average yield for the Washington orchards is given and shows a final production cost of a little more than 3 to 4 cents per pound. Harvesting and

TABLE 42. COST OF DEVELOPING CHERRY ORCHARDS IN MICHIGAN.*

Fluctuating costs per acre for the first six years of a 2.84 acre Montmorency cherry orchard

Items	*Costs First Year (1910)*	*Average Cost Per Year (1911–15)*
Cultivation	$ 7.09	$ 6.28
Hoeing	1.59	1.06
Removal of roots, stones, stumps	2.99	1.89
Intercrop	32.69	3.61
Cover crop	0.26	1.28
Pruning	0.00	1.25
Spraying	2.33	3.45
Resets	16.33	.29
Fertilizer	0.00	1.19
Overhead, labor, interest	24.50	7.56
Grafting	0.00	.30
Total	$87.78	$28.16

* Compiled from: Rogers, A. J., Jr., 1927, Studies in orchard management, with special reference to cherry production. Mich. Agr. Exp. Sta. Spec. Bull. 166.

TABLE 43. ANNUAL COSTS PER ACRE INCIDENT TO DEVELOPING CHERRY ORCHARDS (MONTMORENCY, ENGLISH MORELLO, SWEET VARIETIES) TO BEARING AGE (9 YEARS) IN MICHIGAN *

Items	*Average Cost Per Year*	*Per Cent of Total Cost*
Fluctuating orchard maintenance (labor, culture, fertilizers, etc.)	$38.24	42.5
Supervision	20.00	22.2
Interest	19.09	21.2
Interest on "establishment"	6.15	6.6
Maintenance and upkeep of "establishment"	4.62	5.0
Taxes and insurance	1.86	2.1
Total	$89.94	99.6

TABLE 44. MAINTENANCE (PRODUCTION) COSTS PER ACRE AND PRODUCTION OF CHERRIES IN MICHIGAN, 1916–1925 *

Items	*Mont-morency*	*English Morello*	*Schmidt and Windsor*	*Average*	*Per Cent of Total Cost*
Investment per Acre	$641.32	$647.42	$690.49	$659.74	
Fluctuating costs					
Labor, feed, gas	$ 24.56	$ 24.56	$ 24.11	$ 24.41	15.41
Spraying: labor, materials	23.61	13.13	21.88	19.54	12.33
Commercial fertilizer	7.89	5.73	8.32	7.31	4.61
Replanting	1.22	.29	1.90	1.14	.72
Supervision	16.25	16.25	16.26	16.25	10.26
Interest on land and trees	32.74	30.39	36.12	33.09	20.88
Orchard depreciation	26.29	36.31	19.68	27.43	17.31
Maintenance of "establishment"	15.83	15.83	15.83	15.83	9.99
Interest on "establishment"	8.77	8.77	8.48	8.67	5.47
Insurance and taxes	4.94	4.94	4.50	4.79	3.02
Total	162.10	156.20	157.08	158.46	100.00

packing costs of 2½ cents raise the total cost to approximately 5½ to 6½ cents per pound.

Orchard management for economical production. Yield. The most important single factor in determining the financial success of a cherry orchard is yield. The above statement should not be taken lightly, especially by Eastern growers whose yield is subject to considerable variations due to site, spring frosts, rainfall, and other comparatively uncontrollable factors.

During the years 1916 to 1926 the average "on-the-tree" value of sour cherries in Michigan was 5.15 cents per pound and for

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* *Ibid.*

TABLE 45. COST OF PRODUCING CHERRIES IN WASHINGTON, 1927–1928 *

WENATCHEE VALLEY	YAKIMA VALLEY
Number of farms 27	Number of farms 24
Age of trees 20.13 yrs.	Age of trees 16.2 yrs.
Land invest. per a. $1672.27	Land invest. per a. $1553.00
Equip. " " " 48.18	Equip. " " " 105.16
Irr. " " " 46.66	Irr. " " " 27.56
Av. yield per a. 8093 lbs.	Av. yield per a. 7095 lbs.

Items	*Cost per Acre*	*Cost per Pound*	*Per Cent of Total Cost*	*Cost per Acre*	*Cost per Pound*	*Per Cent of Total Cost*
Maintenance labor						
Pruning	$ 9.41	$0.0012	2.02	$ 10.28	$0.0015	2.20
Brush disposal	2.08	.0002	.45	3.32	.0005	.71
Cultural operations	12.69	.0016	2.72	16.25	.0023	3.47
Spraying	7.16	.0009	1.53	10.77	.0015	2.30
Irrigating	11.09	.0014	2.38	11.37	.0016	2.43
Heating	.97	.0001	.21	12.37	.0017	2.64
Miscellaneous	1.97	.0002	.42	3.87	.0005	.83
Total maintenance labor	45.35	.0056	9.73	68.23	.0096	14.58
Handling labor						
Picking	161.14	.0199	34.56	143.15	.0202	30.59
Hauling (orchard)	14.57	.0018	3.12	11.25	.0016	2.40
Hauling to warehouse	17.00	.0021	3.65	11.30	.0016	2.42
Supervision of harvest	17.80	.0022	3.82	11.35	.0016	2.43
Total handling labor	210.51	.0260	45.15	177.05	.0250	37.84
Materials						
Fertilizer	31.68	.0039	6.80	29.96	.0042	6.40
Spray	8.70	.0011	1.87	9.90	.0014	2.12
Heater fuel	.03			22.06	.0031	4.71
Bee hire	2.82	.0004	.60	5.78	.0008	1.24
Miscellaneous	.17		.64	.70	.0001	.15
Total material costs	43.41	.0054	9.31	68.40	.0096	14.62
Overhead						
Interest on land	100.33	.0124	21.52	93.18	.0131	19.91
Equipment	13.81	.0017	2.96	27.58	.0039	5.90
Irrigation system	6.57	.0008	1.41	5.02	.0007	1.07
Land tax	16.31	.0020	3.50	9.46	.0013	2.02
Water tax	19.44	.0024	4.17	6.19	.0009	1.32
Insurance (liability)	.43	.0001	.09	2.79	.0004	.60
Interest on operating cost	10.08	.0012	2.16	10.02	.0014	2.14
Total overhead	166.97	.0206	35.81	154.24	.0217	32.96
Grand total	466.24	.0576	100.00	467.92	.0659	100.00

* Compiled from: Johnson, N. W., 1930, Economic aspects of the Washington fruit industry. Apricots, cherries, peaches, and pears. Wash. Agr. Exp. Sta. Bull. 238.

sweet varieties 4.8 cents. At these prices, it was necessary to secure 3,300 pounds of sour cherries per acre. The actual production records covering the same orchards as in Table 44 show the following yields. Montmorency cherries, 7 years old, usually produced 1,000 pounds per acre and increased from 10,000 to 15,000 at the age of 12 years. One block on this farm averaged over 20,000 pounds each year when 16 to 19 years old. English Morellos produced 1,000 pounds at the age of 8 years and from 5,000 to 8,000 by the 13th or 14th year. Sweet varieties produced 1,000 pounds per acre at 8 to 9 years of age and increased from 7,000 to 8,000 when 14 years old. Duke varieties produced 1,000 to 2,000 pounds at the age of 9 or 10 years and had increased to 5,000 pounds per acre when 15 years old. Profits in this orchard varied more in relation to yield than in accordance with price.

Life expectancy of trees. The age at which a cherry tree ceases to be commercially productive varies widely according to region, cultural practices, disease, insects, and other factors affecting the vigor of the tree. In New York the expected life of sour cherries is estimated at 30 to 40 years and at 50 to 60 years for sweet varieties. In Michigan the life expectancy of certain varieties is estimated as follows: English Morello, 25 years; Montmorency, 30 years; and Duke and sweet varieties, 40 years.

Variety. Under Eastern conditions the selection of cherry varieties for a planting must be emphasized. In the Michigan study cited in Table 44 the Montmorency variety stood well above all others as a moneymaker. English Morello gave satisfactory results, although in general this variety has not proven profitable in most sections. Early Richmond and Louis Phillipe were not recommended for extensive planting. Windsor, Schmidt, and Bing gave only fair results as did the Duke varieties. Lambert proved to be a liability due largely to its cracking at maturity.

Harvesting costs. The cost of harvesting cherries varies according to region, season, and labor supply. In 1925 in Michigan sour cherries were pulled (without stems) at a cost of 1¼ cents per pound. One cent of this was paid for picking while the remainder represents equipment charges, supervision, etc. Sweet cherries were harvested (with stems) in the same year at a total cost of 4½ cents per pound. In seasons of plentiful production or scarcity of labor it is often necessary to pay a premium of ½ to 1 cent per pound for picking from tall trees. This fact emphasizes the importance of low-spreading trees as an economy measure.

The Plum

Development costs. The cost of bringing a plum orchard into bearing, ranges from $50.00 to $150.00 or even $175.00 per acre in California, exclusive of the price of land.

Production costs. Plum production costs are dependent to a large extent on the yield secured per acre. In California the production varies from 200 to 850 crates per acre with 450 crates considered to be a good yield for a well-managed planting. A crate contains approximately 25 to 26 pounds and a bushel, 56 pounds.

Production costs in California [1] average about $.50 per crate up to harvest time. Harvesting, shipping (to New York), and marketing costs average approximately $1.00 per crate with the following distribution:

Picking and hauling to shed	$0.04
Packing	.07
Shook, nails, labels, baskets, paper, lidding, etc.	.20
Overhead: depreciation, insurance, supervision, etc.	.03
Hauling to railroad	.03
Loading	.03
Freight (per crate of 26 lb.) rated at $1.60 per 100 lb. to N. Y.	.41
Refrigeration	.10
Commission: 7% of gross on auction sales	.12
	$1.03

Prune production costs. The cost of producing prunes varies widely, depending on the ability of the grower and the overhead carried by the enterprise. The investment in drying trays, dipping appliances, lug boxes, and dehydraters fluctuates among different growers and makes an average overhead value difficult to determine.

Some average figures for California [4] are as follows: pruning, $6.90 per acre; brush disposal, $2.31 per acre; cultivation, $11.10 per acre; irrigation, $8.01 per acre; spraying, $4.58 per acre; and propping, $1.53 per acre. Picking costs averaged $11.00 per ton, and drying costs, $15.50 per ton.

The Grape

Production costs and management practices. There are no records available which can be presented to give a typical picture of grape production costs. The few cost account studies which have been published give costs ranging from $50.00 to $160.00 per acre. Yields vary widely and thus cause the cost per ton to fluctuate. The highest yields are not necessarily associated with the highest costs and this adds further complications to the picture.

A few generalizations may be made which should be helpful. (Table 46.) The amount expended for labor and power will usually amount to from 45 to 55 per cent of the total production and harvesting costs, with harvesting accounting for nearly half of the figure. Overhead costs such as interest on the investment, taxes, and depreciation amount to from 20 to 25 per cent. Supplies, such as fertilizer, spray material, and containers will account for about 20 to 30 per cent of the total expense. Miscellaneous items and

TABLE 46. COST OF PRODUCING GRAPES IN LAKE ERIE AND CHAUTAUQUA REGIONS OF NEW YORK, 1915 TO 1919*

Average of 3 vineyards with a total of 34 acres
Yield 2.33 tons per acre

Items	*Cost per Acre*	*Per Cent of Total Cost*
Labor—production		
Pruning	$ 3.73	5.03
Brush disposal	2.04	2.75
Trellis repair	2.24	3.02
Tying	1.75	2.36
Plowing	2.36	3.18
Cultivating	5.82	7.85
Hand hoeing	1.36	1.84
Spraying	0.89	1.20
Miscellaneous	1.88	2.54
Total labor	22.07	29.77
Materials		
Fertilizer	9.39	12.67
Posts, wire, etc.	2.24	3.02
Cover crop seed	1.71	2.31
Spray materials	0.96	1.29
Miscellaneous	0.33	0.45
Total materials	14.63	19.74
Interest on investment	18.00	24.28
Taxes and insurance	3.04	4.10
Harvesting—labor, hauling, containers	16.39	22.11
Total production cost	$74.13	100.00

* Compiled from: Gladwin, F. E., 1920, Studies on the cost of producing grapes. New York (Geneva) Agr. Exp. Sta. Bull. 479.

yearly variations in the above approximations cause them to balance at 100 per cent.

Yield per acre is one of the most important factors in influencing the cost of producing grapes. Operating costs as a rule do not vary in proportion to the yield, since overhead charges and cultural expenses are quite similar in low- and high-producing vineyards. Harvesting costs increase in proportion to increased production, but it is easy to see that when efficient cultural practices are followed, the cost per ton will decline rapidly as the yield increases. Under ·Eastern conditions a grower should secure about 2 tons per acre to cover expenses. A production of 3 to 4 tons will give a moderate profit, while yields of 6 to 8 tons are secured in the better vineyards. The Concord variety produces heavier yields than Delaware and Catawba, but the latter bring a higher price on the market. Yields of 10 to 12 tons per acre are not uncommon in the *vinifera* grape districts of California.

The Raspberry

Production costs and management practices. The cost of producing raspberries varies widely between different growers and different sections of the country. Typical cost data for red raspberry production in Washington are given in Table 47 and for black raspberries in Ohio in Table 48.

Yield. A high yield per acre is of prime importance in this as in other fruits, if satisfactory profits are to be realized. If standard cultural practices are followed and unnecessary expense avoided there will usually be a direct correlation between increases in yield per acre and increase in net profit.

Soil. A good soil is without doubt one of the most important factors in producing high yields and good profits from the bramble planting. Good drainage is essential. Under most conditions a silt loam or heavy sandy loam will give the best results.

Stand of plants. The per cent stand of plants has a direct effect on yield. The most successful growers are those who give attention to details and who constantly replant wherever there are vacancies in the rows.

The Blackberry

Production costs and management practices. Data covering the cost of producing blackberries are not available or are too incomplete to be of sufficient value to include in this text.

TABLE 47. COST OF PRODUCING AN ACRE OF RED RASPBERRIES IN WASHINGTON, 1930

Items	*Ten Farms Having Highest Yields*	*Ten Farms Having Lowest Yields*	*Average of 69 Farms*	*Per Cent of Total Average Cost*
Average yield, lbs. per acre	10,386	2,983	6,234	
Labor—production				
Plowing	$ 8.68	$ 6.20	$ 7.76	1.50
Applying fertilizer	8.19	5.11	6.87	1.33
Training	13.23	9.89	11.27	2.18
Cutting and burning	22.69	14.66	17.45	3.37
Hoeing	16.44	13.63	15.03	2.91
Cultivating	12.09	6.74	9.23	1.78
Total production labor	81.32	56.23	67.61	13.07
Materials				
Fertilizer	28.23	23.71	25.61	4.95
Crates	53.34	16.56	30.50	5.90
Miscellaneous	8.42	3.55	4.80	0.93
Total materials	89.99	43.82	60.91	11.78
Harvesting				
Picking	288.53	92.47	174.70	33.77
Hauling	21.30	8.30	13.51	2.61
Supervision	63.74	26.26	38.77	7.50
Total harvesting cost	373.57	127.03	226.98	43.88
Overhead				
Depreciation	75.00	70.74	72.28	13.97
Interest	91.80	68.00	77.16	14.92
Taxes	14.25	12.55	12.30	2.38
Total overhead cost	181.05	151.29	161.74	31.27
Total	$725.93	$378.37	$517.24	100.00

Economical management practices for blackberries are essentially the same as for raspberries, and have been discussed.

The Strawberry

Production costs and management practices. The cost of producing strawberries varies within rather wide limits depending on the site of the plantation, section of the country, and the managerial ability of the grower. Cost figures are given in Table 49 for establishing

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* Compiled from: Bregger, John T., 1932, Use of the survey method in showing cultural factors in red raspberry production. Proc. Amer. Soc. Hort. Sci. 28:200–205.

TABLE 48. ESTABLISHMENT AND PRODUCTION COSTS PER ACRE OF BLACK RASPBERRIES IN OHIO, 1930*

Average of 8 growers with a total of 40 acres of raspberries

Items	*Cost per Acre*	*Per Cent of Total Cost*
	First Year Costs	
Labor and power		
Fitting soil	$ 5.61	6.29
Planting	4.10	4.60
Cultivation	2.85	3.20
Hoeing	4.50	5.05
Fertilizing	1.20	1.34
Miscellaneous	2.40	2.69
Total labor and power	20.66	23.17
Materials		
Fertilizer	5.66	6.35
Manure	11.00	12.34
Plants	38.00	42.62
Cover crop seed	0.85	.95
Total materials	55.51	62.26
Overhead		
Taxes, equipment, etc.	12.99	14.57
Total costs	$89.16	100.00
Production costs in good fruiting year		
Labor—production		
Cultivation	$5.09	3.10
Hoeing	4.65	2.83
Removing old canes	5.64	3.44
Summer topping	4.26	2.60
Winter pruning	4.14	2.52
Fertilizing	1.20	0.73
Spraying	1.62	0.99
Miscellaneous	1.64	1.00
Total labor	28.24	17.21
Harvesting		
Picking: 1,500 qts. @ 4¢	60.00	36.58
Trucking	12.00	7.32
Supervision	15.85	9.66
Assembling crates	7.20	4.39
Total harvesting	95.05	57.95
Materials		
Fertilizer	7.80	4.75
Manure	7.80	4.75
Cover crop seed	0.85	0.52
Crates and boxes	11.30	6.89
Total materials	27.75	16.92
Overhead		
Taxes, etc.	12.99	7.92
Total	$164.03	100.00
Cost per quart	0.11	

* Compiled from: Shoemaker, J. S., 1932, Cost of development and production per acre of black raspberries. Ohio Agr. Exp. Sta. Ann. Rept. 50:102.

and producing an acre of strawberries in Arkansas, Michigan, and Oregon.

In order to realize the highest possible net return for his effort, the grower should study his costs and management methods to see

TABLE 49. COST OF ESTABLISHING A STRAWBERRY PLANTING

Items	*Arkansas* * *1926*		*Michigan* † *1929–34 Average*		*Oregon* ‡ *1925–26 Average*	
	Cost per Acre	*Per Cent of Total Cost*	*Cost per Acre*	*Per Cent of Total Cost*	*Cost per Acre*	*Per Cent of Total Cost*
Labor—man and horse	$36.89	70.12	$28.53	51.19	$46.35	58.4
Plants	8.81	16.75	10.98	19.70	17.72	22.3
Fertilizer	—	—	5.83	10.46	—	—
Mulch	—	—	3.12	5.60	—	—
Machinery operation	—	—	0.66	1.19	1.23	1.6
Taxes	0.83	1.58	—	—	2.50	3.2
Depreciation on equip.	0.56	1.06	—	—	0.48	0.6
Interest on land & equip.	5.02	9.54	6.61	11.86	10.43	13.2
Miscellaneous	0.50	0.95	—	—	0.57	0.7
Total	$52.61	100.00	$55.73	100.00	$79.28	100.00

COST OF PRODUCING STRAWBERRIES

Items	*Arkansas* * *1926*		*Michigan* † *1929–34 Average*		*Oregon* ‡ *1925–26 Average*	
	1,200 qts. per acre		*1,550 qts. per acre*		*2,170 qts. per acre*	
	Cost per Acre	*Per Cent of Total Cost*	*Cost per Acre*	*Per Cent of Total Cost*	*Cost per Acre*	*Per Cent of Total Cost*
Picking §	$36.00	39.63	$31.00	38.07	$ 58.59	30.6
Other labor—man & horse	8.62	9.49	15.06	18.50	82.49	43.1
Machinery use	3.52	3.88	5.16	6.34	3.76	2.0
Fertilizer	—	—	2.29	2.81	2.34	1.2
Crates, etc.	15.00	16.51	19.04	23.38	2.27	1.2
Taxes	0.58	0.64	—	—	2.59	1.3
Depreciation on invest.	17.54	19.31	—	—	24.92	13.0
Interest on investment	9.08	10.00	7.39	9.08	13.67	7.2
Miscellaneous	0.50	0.54	1.48	1.82	0.74	0.4
Total	$90.84	100.00	$81.42	100.00	$191.37	100.00

* Compiled from: Branner, C. O., and Dickey, J. A., 1927, Strawberry production and marketing in Arkansas. Ark. Agr. Exp. Sta. Bull. 218.

† Compiled from: Peacock, Neal D., 1939, The relative importance of various factors influencing profits in strawberry production. Mich. Agr. Exp. Sta. Tech. Bull. 162.

‡ Compiled from: Schuster, C. E., and Burrier, A. S., 1929, Costs and practices in strawberry production in the Willamette Valley, Oregon. Ore. Agr. Exp. Sta. Tech. Bull. 245.

§ Prices paid for picking were as follows: Arkansas, 3.0¢ per quart; Michigan, 2.0¢ per quart; Oregon, 2.7¢ per quart. In some regions the price is as low as 1.0¢ per quart.

what economy measures may be followed. The factors discussed below have been found to be the most important in influencing economical production.[7]

Yield. Here again a high yield per acre is one of the best ways of reducing the cost of producing strawberries. The following table illustrates this point. Similar data showing a reduction in cost per pound as the yield increases could be cited for other producing regions. (Table 50.)

TABLE 50. THE EFFECT OF YIELD ON THE COST OF STRAWBERRY PRODUCTION IN OREGON

(*From Schuster and Burrier*)[7]

(1925 and 1926 combined averages)

Yield per Acre Pounds	*Average Yield per Acre Pounds*	*Average Cost per Acre*	*Average Cost per Pound*
Below 2,000	1,372	$126.00	$0.093
2,000 to 4,000	2,928	178.00	.060
4,000 to 6,000	4,751	254.00	.054
6,000 or over	6,960	344.00	.050

Note: Approximately 1.5 pounds equals one quart.

Under Michigan conditions [6] yields of 3,000 to 4,000 quarts per acre are considered satisfactory and profitable. Yields as high as 6,000 to 8,000 quarts per acre are not uncommon.

Variety. There is an appreciable variation in the yield and quality of different varieties of strawberries. Varieties should be selected which are heavy producers and which have a market demand.

Number of plants per acre. Under the hill system of planting, the number of plants per acre is fixed when the plantation is established. The number of plants allowed to develop in the matted row, however, may be controlled by the grower and is one of the important factors affecting yield. The exact number of plants which will give the best return depends principally on the fertility of the soil, moisture supply, and the inherent vigor of the variety. In most cases 5 or 6 plants per square foot is a good number. Plants which grow vigorously should be farther apart as should plants located on poor or dry soils.

Season of planting. Data collected in Ohio indicate that plants which are set out in early spring produce larger and more fruitful runner plants than when set in late spring. Weather and soil conditions seem to be more suitable for vigorous growth when the planting is done at the earlier date. Similar results have not been secured in Michigan which would indicate that this may be a local and not a universal factor.

Miscellaneous factors affecting production costs. High overhead costs due to expensive equipment and land are a drain on an enterprise and should be avoided if a net profit is to be realized.

The size of the plants which are set out is not so important as is freedom from diseases and insects.

Although soil drainage, fertility, and moisture are of prime importance, the slope of the land should also be given consideration. A site which has suitable air drainage to prevent spring frosts may have a decided influence on profits in many seasons.

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